

Leon M. Lederman, Director  
Fermilab

Dear Leon:

This is a Letter of Intent to continue the series of heavy quark experiments in the Tagged Photon Spectrometer. We will propose a two running period experiment aimed at the hadroproduction of beauty and charm particles.

Most of us are currently engaged in E769, the hadroproduction of charm with tagging of the incident  $\pi$ , K and p's. We have recorded over 200,000,000 physics events and have begun reconstruction of the data on the Cyber and ACP systems. This run should see the completion of much of the program outlined in the E769 proposal. Nevertheless, we want to leave room for extending this charm program. At the same time, we are anxious to begin work on a similar effort for beauty physics.

With these thoughts in mind, we make a primary goal of a new experiment the extension of our trigger capability and the collection of a sufficient sample of beauty decays to:

1. separately measure the lifetimes of charged and neutral beauty mesons
2. measure the beauty hadroproduction cross-section
3. contribute to branching ratio measurements of beauty
4. measure  $B/\bar{B}$  mixing, hopefully in  $B_d$  and  $B_s$  separately.

While doing this, we will collect (in parallel) sufficient charm decay data to follow up on interesting questions raised by the analysis of E-769 data. At the anticipated higher energy of the next runs, we should be able to confront directly recent charm baryon production and other unexpected results (e.g., the U).

The new experiment will use the existing microstrip vertex detector and powerful spectrometer which were successfully demonstrated for photoproduction in E-691 and are currently in use for E-769. We use accurate vertex measurements to select the events of interest and to concentrate reconstruction histograms on downstream vertexing tracks. This both enriches the charm and beauty samples and minimizes the combinatorial backgrounds which have plagued heavy flavor hadroproduction experiments of the past.

The existing Tagged Photon Spectrometer detectors are adequate for the next experiment. The major problem for the beauty experiment is collecting a sufficient number of analysable events to reach the goals. All of the proposed upgrades for the experiment are directed at this problem (while being useful for the charm data as well). These upgrades include:

1. increased beam energy to the Tagged Photon Laboratory
2. reduced event readout dead-time
3. on-line filtering of events in our ACP data acquisition system
4. use of an increasingly selective hardware trigger.

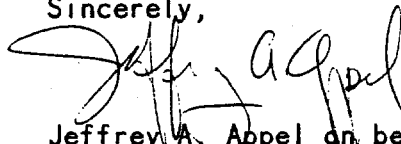
An upgrade of some of the front-end electronics and data acquisition system is desirable. These upgrades make use of existing hardware types and the architecture of the system is identical to that in use in E-769.

During the next Fixed Target run, the new experiment requires the first and emphasizes the second and third items in the above list of 4 upgrades. We will make extensive tests and early use of the trigger system which is essential for a successful beauty program. We note that intensive work on the trigger has already begun using the existing E769 data and in on-line tests during the present run. During the running period following the first, the experiment would make use of an improved hardware fast trigger. We will propose that the experiment run in the next two Fixed Target periods, beginning with the highest energies possible in the Tagged Photon Laboratory beam line without additional civil construction (perhaps 500 GeV).

We are studying the rates and efficiencies for reconstructed beauty decays. We have evidence that with a modestly upgraded version of our apparatus we will be able to reconstruct sufficient beauty decays to achieve at least cross section and lifetime measurements. The testing of our ideas related to multiplicity jump and high  $p_t$  electron triggers is in progress. Implementation of these can significantly increase the number of detected decays and speed up access to our additional physics goals. Furthermore, we are studying the possibility of parallel running with the Yale/Fermilab streamer chamber. This device is capable, with a sufficiently selective trigger, of taking interesting heavy flavor data which is complementary to that of the purely electronic detector.

We are delaying our formal proposal until the next PAC meeting in order to include the results of the trigger tests which we are doing during the running of E-769. While we are convinced that even the minimal program outlined above would significantly advance the knowledge of beauty particle production and decay in the next running period, we recognize the crucial importance of developing better triggers for beauty. No other experiment is in a position to continue as successful a program of heavy flavor physics, building on and extending our techniques and knowledge. This applies to both charm and the beginning of what may be a longer than anticipated march towards beauty.

Sincerely,



Jeffrey A. Appel on behalf of

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**Fermilab**

FERMILAB-Proposal-0791

March 2, 1988

Leon M. Lederman  
The Directorate

Dear Leon,

Enclosed is a proposal (entitled "P791, Continued Study of Heavy Flavors at TPL") for your consideration and review by the PAC at its next meeting.

Pleased by early charm signals already evident (in a tiny fraction of the data from E769) and the proven ability of the TPL spectrometer to identify and reconstruct charm, we are anxious to continue analysis, yet also aware of the potential to continue doing exciting physics. The enclosed proposal, by a subset of E769 plus additional new collaborators, is our response to the above potential. We offer the possibility of an important extension to the understanding of rare charm decays and the best opportunity to do a significant start on beauty physics. Furthermore, because of the unique features of the proposed experiment, the possibilities of real surprises should not be minimized.

We look forward to your early consideration of this proposal and the granting of approval which will make it possible to be fully ready for the next fixed target running period.

Sincerely

Jeffrey A. Appel  
for the Collaboration

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Encl.

**P791**

**CONTINUED STUDY OF  
HEAVY FLAVORS AT  
TPL**

A Proposal to Fermilab  
March 7, 1988  
by

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## I. Proposal Summary:

This is a proposal to continue the series of heavy quark experiments in the Tagged Photon Laboratory (TPL). We propose a two-phase experiment aimed at the eventual study of beauty particles and their hadroproduction. However, we anticipate that very large numbers of interesting charm particle events will be observed along the way.

In the first phase of the experiment, to be run in the next fixed target period, we anticipate accumulating approximately 100,000 fully reconstructed charm particles and a few 10's of fully reconstructed beauty particles. Additional information on beauty production will come from larger samples of less than fully reconstructed beauty decays. For charm, Phase I represents an order of magnitude improvement in signal over E769. In the second phase of the experiment, to be run in the fixed target running period following the upcoming running period, we anticipate accumulating yet another order of magnitude more charm and beauty decay.

The philosophy of this effort is a continuation of the open trigger strategy of E691 and E769. This implies accumulation of very large amounts of data for efficient off-line filtering and analysis using ACP type microprocessor farms. This philosophy is distinct from and complementary to experiments with specific final state triggers.

The very large sample of open charm states will be used to study rare charm meson decays, charm baryons, production correlations and to measure improved values for lifetimes and mixing limits. We are confident of being able to attack these problems based on our first looks at E769 data. We see a signal to background ratio comparable to that achieved in the photoproduction data of E691. This earlier TPL experiment has already demonstrated that the apparatus is capable of producing physics results of a quality formerly imagined only in colliding  $e^+e^-$  experiments. We expect with the new experiment to be able to overcome the statistical limitations of previous efforts.

During a short portion of the run we will operate a high resolution streamer chamber in conjunction with the basic electronic experiment. This will be a sufficient period of time to demonstrate the utility of open triggers for streamer chamber experiments, prove the chamber's physics analysis capability and maintain the option of streamer chamber use for beauty (should the combination of cross-section and advanced trigger capability make this attractive). At the same time, the streamer chamber exposure will provide a unique and complementary look at some interesting charm physics questions. These include cross-sections which can be used to convert ratios of branching ratios to absolute branching ratios, charm production correlations and negative Feynman  $x$  capability. These are described in more detail in the Appendix to this proposal.

The eventual goal of the experiment is to collect a sufficient sample of beauty decays to:

1. separately measure the lifetimes of charged and neutral beauty mesons
2. measure the total and differential beauty cross-section
3. contribute to branching ratio measurements of beauty

While these eventual physics aims will be addressed in Phase I, we conservatively expect that we will obtain only crude numbers. Learning the most effective way to proceed will only come through experience. For this reason we are explicitly planning the two-phase approach outlined above. The apparatus modifications proposed for the next run are all aimed at being useful without change for both phases of the experiment.

The experiment will use the same techniques which were successfully demonstrated for photoproduction in E691 and hadroproduction in E769. We use accurate vertex measurements to select the events of interest and to concentrate reconstruction histograms on downstream vertexing tracks. This both enriches the charm and beauty samples on tape and minimizes the combinatorial backgrounds which plagued heavy flavor hadroproduction experiments of the past.

The basic Tagged Photon Spectrometer detectors (Figure 1) are adequate for the next experiment. The major problem for the experiment is collecting a sufficient number of analyzable events to reach the goals. All of the proposed upgrades for the experiment are directed at this problem. These include:

1. increased beam energy to the Tagged Photon Laboratory
2. reduced event readout dead-time
3. improved acceptance, redundancy and resolution for the silicon microstrip detector system
4. examination of many more interactions using either/both higher data recording rates or/and on-line filtering of events before writing to tape

Phase I of this experiment emphasizes charm physics and a first look at beauty hadroproduction. The system would be run at the highest energies possible in the beamline to the Tagged Photon Laboratory without additional construction, 500 GeV. In Phase II the beamline should be upgraded to transport 800 GeV pions or 1 TeV protons to the laboratory.

The primary trigger for the experiment will be a global transverse energy from the forward calorimeters. This has proved to be successful in previous TPL experiments on heavy flavor. This trigger will be basic to both the electronic and streamer chamber parts of the experiment. The streamer chamber event trigger will however, also include a fiducial volume trigger as described in the Appendix.



## II. Physics Objectives

This experiment aims to go clearly beyond E-691, Mark III, ARGUS, CLEO and other charm experiments in the amount of charm events to be reconstructed. With a data set at least a factor of ten larger than E-691 and with a better silicon vertexing system, we expect to enter a new realm of charm physics. The emphasis on high statistics, better resolution and lower backgrounds than E-691 will enable us to measure many new modes of charm meson and charm baryon decays, to measure charm particle lifetimes precisely, to improve  $D^0$ - $\bar{D}^0$  mixing limits substantially, to better understand charm production and to make progress towards beauty physics in a hadron environment.

In the following sub-sections we elaborate on these assertions, while also referring the reader to the section on comparisons between charm experiments below. As the section on rates explains, we expect about 100,000 fully reconstructed charm events, as opposed to E-691's 10,000. We implicitly use this factor of 10 in the following discussion. For instance, those of E-691's signals which are at the  $2\sigma$  level will become completely unambiguous (some of the  $\Lambda_c$ ,  $D^{**}$ , semileptonic signals — especially unpublished results).

### A. CHARM DECAYS

E-691 and other experiments have begun to measure branching ratios which shed light on the various mechanisms at play in charm decay. The pattern of  $D^0$ ,  $D^+$ ,  $D_s^+$  and  $\Lambda_c^+$  lifetimes<sup>1</sup> point to dominant spectator diagrams without much colour-suppression and small contributions from the exchange and annihilation diagrams for D mesons. However, none of these assertions are completely proven and there remains much else to do for a high-statistics experiment like P-791.

The role of final state interactions is one such example. It appears from decays like the  $K\pi$ ,  $K^*\pi$  and the  $K\rho$  that final state interactions are important.<sup>2</sup> Less well measured is the  $K^0$ - $\bar{K}^0$  decay mode of the  $D^0$ .<sup>3</sup> Finally, E-691 sees a small branching ratio for  $D_s^+ \rightarrow \pi^+\pi^-\pi^+$  relative to  $\phi\pi^+$  and even less evidence of the  $D_s^+ \rightarrow \rho\pi^+$ .<sup>4</sup> This is interpreted as meaning that annihilation diagrams do not play a major role, but again final state interactions could be invoked to explain the small branching ratios. However observation<sup>5</sup> of the  $\bar{K}^0\phi$  decay of the  $D^0$  indicates the importance of non-spectator decays.

P-791 proposes to measure these and other modes which become feasible with a tenfold increase in statistics. The high statistics also allows Dalitz plot analyses of modes such as  $KK\pi\pi$ ,  $KK\pi\pi\pi$ , ... to determine the fraction of decays that come from PP, PV and VV decays (P – pseudoscalar, V – vector). A dominance of two-body modes is motivated by simple considerations and facilitates calculations of many branching ratios.<sup>6</sup> We expect

to measure most modes with expected branching ratios of  $\sim 1\%$  and some modes with expected branching ratios only a little larger than  $0.1\%$ . The  $K^- a_1^+$  and  $K^{*+} K^{*-}$  are examples of the former and the modes  $\rho\rho$  and  $K^{0*}\pi^+$  are examples of the latter branching ratios.

Another interesting area of charm decays is semileptonic modes. Higher resolution and lower backgrounds help these decays as much as the higher statistics because the missing neutrino energy degrades resolution considerably. Because of poor statistics to date even the modes observed so far such as the  $K^- e^+ \nu_e$ ,  $K^- \pi^+ e^+ \nu_e$  and the  $\bar{K}^{*0} e^+ \nu_e$  will gain from higher statistics. In addition, we hope to be able to see  $\rho e^+ \nu_e$ , the KM-suppressed  $\pi^- e^+ \nu_e$  mode (and learn about the KM-matrix element  $V_{cs}$ ) and similarly to observe the  $D_s^+$  decays into  $\phi e^+ \nu_e$  and  $\eta e^+ \nu_e$ . A study of semileptonic decays could point to extra generations through lack of unitarity in the KM matrix. In any case, we expect to measure form factors in the decays and polarization of the  $K^*$ s. Finally, with higher statistics we could extend these studies to the semi-muonic modes and possibly even look for purely leptonic decays such as  $\mu^+ \nu_\mu$  and  $\tau^+ \nu_\tau$  which directly yield the pseudoscalar coupling constants.

Other decay modes of interest include charm-changing neutral currents (for which we can improve the E-691 limits), singly and doubly Cabibbo-suppressed decays and decays from other interesting diagrams (such as destructive Pauli interference, Penguin diagrams, Hairpin diagrams etc. — see ref. 7 for a recent review). We also feel that entering the new regime of small branching ratios will inspire theorists to revisit charm decays and predict even more branching ratios and identify their interesting features.

While there has been much work in the field of charm meson decays, there is still a lack of good statistics for charmed baryons. We expect to confirm and accurately measure the relative branching ratios of the  $\Lambda_c^+$  into  $pK^-\pi^+$ ,  $pK_s^0$ ,  $pK_s^0\pi^+\pi^-$ ,  $\Lambda\pi^+$  and  $\Lambda\pi^+\pi^+\pi^-$ . Further, we can search for other modes for the  $\Lambda_c^+$  decay and combine the observed  $\Lambda_c^+$  with pions and kaons to look for the  $\Sigma_c$  multiplet. There is controversy over the mass of at least two of the members of this multiplet<sup>8,9</sup>. Finally, we should be able to see the  $\Xi_c^+$  and other charmed baryons if they decay into simple charged modes and extend the search for the  $D^{**}$  mesons.

## B. $D^0$ - $\bar{D}^0$ MIXING

The Standard Model predicts strong suppression of  $D^0$ - $\bar{D}^0$  mixing due to the s-quark dominance in the well-known box diagram in contrast to the  $K^0$ - $\bar{K}^0$  system where the c-quark dominates. As a consequence, it is widely assumed that measurement of a substantial

rate of  $D^0\text{-}\bar{D}^0$  mixing would be a signal of new physics beyond the Standard Model. The Standard Model predicts the correct phenomenology of the  $K^0\text{-}\bar{K}^0$  system, at least at the order of magnitude level, whereas some extended technicolor theories and left-right symmetric theories have failed this test<sup>10</sup>. In the case of  $D^0\text{-}\bar{D}^0$  mixing, it is also possible to produce a flavor-violating ( $\Delta c = 2$ ) transition by a product of weak-interaction processes to specific mesonic intermediate states<sup>11</sup>. These "doubly Cabibbo suppressed decays" (DCSD's) are expected to occur at a rate one or two orders of magnitude greater<sup>11</sup> than box-diagram predictions.

The current interest in  $D^0\text{-}\bar{D}^0$  mixing stems from the possible observation of a high-level of such mixing from Mark III<sup>12</sup> whose 3 "mixed" events on a background of  $0.4 \pm 0.1 \pm 0.1$  (out of 162 "unmixed" events) can be interpreted as mixing at the 1.5% level. E-691 however, find that  $D^0\text{-}\bar{D}^0$  mixing is below 0.4% at the 90% CL. The E-691 result is further strengthened by the fact that they are sensitive to the time development of mixing, as would be P-791. E-691 is only about a factor of 2-3 away from the sensitivity required for observing DCSD's. P-791 should therefore not only improve  $D^0\text{-}\bar{D}^0$  mixing limits but also be able to observe DCSD's. We expect P-791 to be sensitive to mixing at the 0.1% level.

In summary, if mixing is not observed, P-791 should set a limit below the theoretically expected level of DCSD's. If it is observed, the P-791 analysis will allow separation of box-diagram mixing from DCSD's. In this case, the branching ratio for wrong-sign decays would be measured for the first time.

### C. PRECISION LIFETIME MEASUREMENTS

E-691 has contributed the best lifetime measurements of charm particles to date. Their measurements of the  $D^+$ ,  $D_s^+$ ,  $D^0$  and  $\Lambda_c^+$  lifetimes are  $1.090 \pm .030 \pm .025$  ps,  $0.47 \pm .04 \pm .02$  ps,  $0.422 \pm .008 \pm .010$  ps and  $0.22 \pm .03 \pm .02$  ps<sup>1,14</sup> respectively. As can be seen, these lifetimes are beginning to be limited by systematic errors. It can be asked whether the factor of 10 increase in statistics anticipated will be thwarted by insurmountable systematic effects. The answer is clearly no, if we examine the sources of E-691's systematic effects. The major errors come from uncertainties in the absorption and scattering cross-sections of the charm decay products (and even the charm itself!). These uncertainties and z-dependent acceptance corrections both become small with the simple expedient of switching to a foil target. Further, with a high-resolution Silicon system, we should comfortably be able to keep the systematic errors below the statistical errors.

A precision measurement of lifetimes will set the standard for several years and could inspire theorists to calculate all the decay diagrams. In particular, if the non-spectator

diagrams which affect the equality of the ratio of  $D^+$  and  $D^0$  lifetimes and the ratio of their semileptonic branching ratios are calculated, an important relation in charm decays can be precisely tested.

#### D. PRODUCTION OF CHARM

While charm production studies are not expected to be the major impetus of this experiment, the sample of hadroproduced open charm states written to tape will be at least an order of magnitude larger than any previous or concurrent sample, including that from E-769. This statistical power can be exploited in making detailed comparisons with the various theoretical models in regions of the kinematic variables where there have previously been only a small number of events. Also, windows to as yet unexplored kinematic regions will be opened up by the increased acceptance.

The QCD fusion model is unable to accommodate a leading component to charm hadroproduction or an  $A$  dependence of the form  $A^\alpha$  where  $\alpha$  is not 1. E-769 should certainly be able to put these measurements on solid ground. However the statistics at large  $x_F$  may not be large. P-791 will enable a sensitive measurement in this kinematic region. The increased acceptance will extend the  $p_T$  region that can be explored. QCD is expected to give better predictions at high  $p_T$  as already established for QCD jets above  $\sim 5$  GeV.

Statistics should be sufficient to allow a measurement of production polarization for one of the more copious states of non-zero spin. Hyperons containing strange quarks show large polarizations<sup>15</sup> in production. As yet there are no theoretical models which explain this phenomenon.

The number of events for which both charm particles will be accepted is expected to be as much as 20 times larger than the sample obtained in E-691. E-691 expects to publish results based on 100 charm pairs and E-769 should similarly expect to see about 70 charm pairs. This is based on the measured LEBC charm cross-section<sup>16</sup> and assumes identical acceptance for E-691 and E-769. If we make the same assumption of acceptance we obtain 700 charm-pair events for P-791, while another factor of 2 in acceptance increase will lead to 1400 such events. We expect another factor of 2 due to the improved geometric acceptance alone (see tracking upgrade section below) and another improvement due to the higher beam energy.

Of compelling interest in these data will be studies of associated production for which only a handful of events have been seen to date<sup>17</sup> and measurement of the average  $p_T$  of the charm pair which appears to be much larger than expected in the only measurement

yet attempted.

## E. BEAUTY PHYSICS

This experiment emphasizes an open geometry, high statistics, large acceptance and fine resolution for lifetimes. These features are ideally suited for charm physics, but are also essentially what is needed for a first beauty experiment. We expect to measure B lifetimes, the  $B^0$ - $B^+$  lifetime difference, the total and differential beauty cross-sections, fully reconstruct some decays and perhaps even study the time evolution of mixing. Because the B-mesons are boosted to  $\gamma$  values of  $\sim 30$ , their reconstruction is made easier than at collider energies.

For a run lasting  $2 \times 10^6$  seconds, a 5% target, a 2MHz beam and a  $\sigma_{b\bar{b}}/\sigma_{TOT} = 3 \times 10^{-7}$  at 500 GeV, one obtains a total production of 60,000  $B\bar{B}$  pairs. The total trigger efficiency and livetime effects reduce this number to  $\sim 50,000$   $B\bar{B}$  pairs.

For total cross-section studies, it is enough to exploit the semileptonic branching ratio or the branching ratio into  $D^{*+}$  mesons. For most other studies, it is necessary to fully reconstruct decays. Assuming .001 reconstructed B mesons per produced B event, we are left with only 50 fully reconstructed decays. This underscores the importance of background reduction (implying a high-resolution and high-redundancy silicon system). It is extremely hard to model the backgrounds which could be large. The experiment should provide a direct measure of these backgrounds and our data should be a fertile testing ground for B-trigger ideas because of our open geometry.

However, the topological branching ratio into leptons and  $D^{*+}$  mesons can be utilized to obtain a total cross-section, lifetimes and even some differential cross-section information. The useful topological branching ratio into  $D^{*+}$  is about 1.7% and the fully reconstructable semileptonic modes are 0.9% and 1.4% for the neutral and charged B mesons respectively. The inclusive cross-section into leptons is known to be about 22%, with about half that number at high  $p_T$  ( $> \sim 1$  GeV). Thus, we should see about 7000 events with high- $p_T$  leptons from B mesons and about 700 events with two high- $p_T$  leptons. Finally, there are expected to be 1.15 charm particles per B meson decay. We could thus also obtain the B cross-section from the number of D mesons which do not point back to the primary vertex.

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### III. Required Upgrades

#### A. Introduction

The three major upgrades requested in this proposal are an order of magnitude increase in the data acquisition, an increase in coverage and redundancy of the silicon microstrip detector system (SMD), and an increase in the beamline energy. These will help us obtain more heavy flavor events, particularly those where both heavy flavor particles can be detected. In addition, the greater redundancy and higher resolution of the SMD system will effectively increase the number of charm events detected and will reduce backgrounds. Doing high statistics charm and catching any beauty events requires either an increase in the E769 data acquisition rate, or trigger enrichment, or both. We propose to continue the successful direction of experiments at TPL, which is to depend as little as possible on substantial trigger enrichment, and to apply our efforts instead to improving the data acquisition system already developed for E769.

#### B. Data Acquisition System

The philosophy of TPL experiments has been to avoid any dependence on trigger processors, due to cost, manpower, and workability. If an impact parameter trigger processor were used for P791 (e.g. based on finding tracks in silicon microstrips), it would have to operate exceedingly fast. A third level trigger (consisting of an ACP processor farm, for example) might work; but would still require an upgrade to a faster front-end readout, and would have the potential to slow down the data taking and to cause possible trigger biases. Use of an offline farm of ACP processors avoids these problems. We currently estimate that 120 of the Motorola 68020 ACP processors will be able to analyze the 450 million events taken by E769 in six months. The projection is based on the assumption that a fast software filter, which demands the possibility of multiple vertices, will reduce the total reconstruction time by a factor of 4. P791 will use a similar offline filter in upgraded ACP processors. (The ACP group is currently developing a processor, based on the MIPS chip [1], which has been benchmarked to be 10 times faster than what is now used). The obvious problem of storing large amounts of data at reasonable cost is addressed below in section 6.

In order to achieve the physics goals of Phase I of the proposal, we need to increase the data taking rate by a factor of 12. Phase II can attain an additional factor of 4. The E769 DA system [2-5] currently logs 400 events (each 4 kilobytes long) per spill-second. The current E769 front end readout speeds are roughly 300 to 900 microseconds. To write 20,000 events per spill-second with 30% dead time in Phase II, P791 requires front end readout speeds of 15 microseconds. Sten Hansen of the Fermilab Physics Dept. is developing, for D0, TDC's and ADC's which are read out in 10 to 20 microseconds. We propose to use these devices, and upgrade the DA system to operate at the higher data taking rates.

The overall architecture of the new system is shown in Fig. 2. The digitizing electronics are triggered to read out, and the data passed in several parallel data streams. A busy signal raised during digitization prevents further triggers. The event fragments are stored in FIFO memory buffers on each data path. The buffers have the capacity to store a whole spill of data. The data in each FIFO moves on, during the spill and interspill, to dual port buffers in a VME crate, where event building takes place. By placing the large amount of memory upstream, the event building can occur continuously, and not just during the spill. The assembled events are then sent to an I/O port and onto tape. Selected events are also sent to a VAX for monitoring. The boss CPU supervises the system. At each stage in the system, Busy/Ready signals are sent from downstream devices to upstream devices, e.g. if the tape is still busy, the dual port buffers are forbidden to receive any more data; if any of the FIFO's fills up, it signals the associated digitizer, which then holds off experiment triggers. This is exactly the scheme employed successfully in E769.

The following sections describe each of the parts in more detail. Note that we are currently planning to extend the data acquisition architecture which has proven to be very successful and trouble free during the E769 run. We present one implementation of this scheme, but others are also being considered. We use the presented scheme as a proof of principle and to estimate costs.

### 1. New TDC Electronics

E769 uses one LeCroy 4298 TDC channel for each of 6304 drift chamber wires. In a typical event, only 5% to 10% of these wires are actually hit and need to be digitized. The TDC's being developed by the Fermilab Physics Dept. perform the data sparsification before digitizing, making the readout time of the devices faster than the LeCroy units.

The new electronics handles 64 channels per card. Two time to voltage converters are provided per channel to record double hits. One flash ADC is then used to digitize only the channels that are hit. Fast analog CMOS switches are employed to multiplex each channel without biasing the charge that is being read out. The digitization time is 1 microsecond per hit. The time to get the address of the channel and be read out is less than 50 nsec. The flash ADC which looks most promising is the 11-bit Micro Power Systems [6] MPS7685 (\$36 each in 100's). The TDC modules fit into a Eurocard crate which also contains a crate controller similar to the Smart Crate Controllers used in E769. The output from the controller goes onto an RS-485 bus at a rate of up to 40 MB/sec.

### 2. New ADC Electronics

E769 uses LeCroy 2280 and 2249 ADC's to digitize 536 calorimeter and Cerenkov channels, of which about 40% are hit in a typical event. Like the LeCroy TDC's, digitization occurs first. The new ADC electronics being developed by the Fermilab Physics Dept., which perform sparsification before digitizing, will be faster than the LeCroy system.

Each channel in the new system stores the charge received during an event gate. A discriminator is used to determine if a user set level is passed; if so, the channel is digitized. As in the TDC's, fast analog CMOS switches are used for multiplexing. Twelve bits of dynamic range are required. To achieve this one could either use two 11-bit ADC's in series such as the MPS7685 used by the TDC's, or one could use a single 12-bit flash ADC such as the Crystal Semiconductor [7] CS5212 (\$185 each). Each module will have 64 channels multiplexed to two ADC's, i.e. 32 channels per 12-bit ADC. The modules fit into the same type of crate as the TDC cards, and use the same type of controller.

### 3. New Silicon Microstrip Readout

E769 has about 9000 silicon microstrip channels. When a channel is hit, a bit is set in a shift register on an amplifier-discriminator card. Eight scanners are used to shift the bits out in parallel and to sparsify the data. A typical event has 200 hit channels, and shifting a bit requires 100 to 200 nanoseconds. If the scanners are modified to shift 150 bits at 100 nanoseconds per bit, the SMD's can be read out in 15 microseconds without changing the current amplifier-discriminator cards; only the scanners need to be upgraded. A CAMAC based scanner is being developed by Fermilab for E665. Sixty such scanners would be required. Four scanners fit in a module, so 15 modules would be housed in three CAMAC crates. About 200 16-bit words then need to be read out of the CAMAC crates. The current E769 Smart Crate Controllers can be adjusted to read out at faster than normal CAMAC speeds, up to 200 nsec per 16-bit word, if the modules in the crates are capable of this.

Another possibility is the silicon microstrip readout system being developed by the Fermilab Research Division for E771. This system puts the required amplification, delay, discrimination, buffer and zero suppression functions onto a custom chip.

### 4. FIFO Memory Buffers

The data from each crate of TDC's, ADC's and SMD scanners are stored in a FIFO memory buffer. If the tape writing speed is kept at 8 MB/sec during the 34 second interspill, then a total of  $34 \times 8 = 272$  MB total of memory is needed. If there are 10 crates of data being read in parallel, then each data line needs about 28 MB of memory. Buffering the data before rather than



after event building allows the event building to proceed not just during the spill but during the interspill as well.

Al Baumbaugh and others [8,9] have developed a simple FIFO memory system for E687. Four MB of memory fit on each electronics card in the form of 256K dynamic RAMs. We would need an average of seven memory cards plus a FIFO controller card for each of the 10 crates on the parallel data paths. The inputs and outputs of the system are simple and run at a speed of at least 60 MB/sec. Each uses a bus with 32 data lines, one ground, one strobe; the levels are TTL.

## 5. VMEbus Event Builder

In E769, event fragments move from seven Smart Crate Controllers to seven dual port double buffers. ACP CPU boards assemble the event fragments by collecting them out of the buffers and then send the assembled events to a tape controller. The buffers only allow one word at a time to be moved. Block transfers, which would be faster, are not supported. There are at least two ways to speed the process up :

- a) Replace the buffers with ones that allow block transfers. The Ironics [10] IV-3272 VMEbus Full Speed Data Transporter looks like a good candidate for this function. It has an RS-485 interface.
- b) Do not move the data over the VMEbus twice as it is done in E769. This means that the tape controller should reside on the same board where events are assembled. There are several CPU boards available with Small Computer System Interface (SCSI) ports (e.g. the Omnibyte OB68K/VSBCI [11] ). We need to find one with adequate performance. Alternatively, we might use an SCSI controller board with enough memory to buffer a few events.

## 6. Tape Drive System

How does one write to tape at 8 MB/sec? The following table presents 5 options. The first option is just to use more 0.6 MB/sec 9-track drives like we used in E769. The total cost of the tape needed for P791 rules out this option, as well as the IBM 3480 cartridge drives. The Haystack Observatory [10] tape drive is to be used by the Very Large Baseline Array; it looks promising, but only one prototype exists today. Both the Honeywell [11] Very Large Data Store (VLDS) and the Exabyte [12] EXB-8200 are commercially available, although Honeywell has only shipped two dozen drives so far. The tape cost per 1000 hours of running is reasonable in both cases, and actually quite cheap for the Honeywell.

The number of Exabytes required is somewhat unwieldy due to its low 0.25 MB/sec speed. It does have a 1/4 MB buffer that accepts data at 1.5 MB/sec. At some point Exabyte may introduce a new version with double the speed and twice the density. Honeywell expects to upgrade their drive from 2MB/sec to 4 MB/sec in the near future. The high cost of the Honeywell reduces the number of drives that can be purchased; it is only cost effective in high speed applications. We intend to choose either the Exabyte or the Honeywell drives. The current delivery time quoted for the Honeywell is seven months, while the Exabyte is packaged and sold now by numerous vendors [15].

Both the Honeywell and Exabyte are available with a SCSI interface. A SCSI to VME controller called the Rimfire 3510 is made by Ciprico [16]. It will pass data on the SCSI bus at between 2 and 5 MB/sec. Either one Honeywell or about 4 Exabytes would be connected to such a controller. A number of other companies also make SCSI controllers for this and other buses.

# TAPE DRIVE COMPARISON

DRIVE	9-TRACK	IBM 3480	EXABYTE	HONEYWELL	HAYSTACK
tape width	1/2"	1/2"	8mm	1/2"	1"
tracks	9	18	819 TPI	400TPI	512
# of heads	9	18	1	2	~32
tape length	2400'	540'	360'	807'	28000'
bits/inch/track	6250	18936	~40,000	~40,000	~35,000
speed (MB/sec)	0.6	3	0.25	4	24
# of drives	13	3	32	2	1
spare drives	3	1	4	1	1
\$/drive	\$10,000	\$50,000	\$3210	\$39,900	\$80,000
drive cost (includes spares)	\$160,000	\$200,000	\$115,560	\$119,700	\$160,000
GB/tape	0.16	0.22	2.3	5.2	750
time/tape	4.5 min	1.2 min	2.5 hrs	22 min	22 hrs
tape changes/hr	175	150	13	6	1/22
\$/tape	\$10	\$12	\$6	\$4	\$800
tapes/1000 hrs	175,000	150,000	13,000	6000	45
tape cost	\$1,750,000	\$1,800,000	\$78,000	\$24,000	\$36,000
TOTAL	\$1,910,000	\$2,000,000	\$193,560	\$143,700	\$196,000

## 7. Summary and Cost

We propose to upgrade the E769 DA system from 400 events per spill-sec to 5000 events per spill-sec in Phase I, and by an additional factor of 4 for Phase II. We intend to upgrade our front end electronics by multiplexing many channels into a single flash ADC. 280 MB of FIFO memory is required in Phase I to buffer a spill. New dual port buffers, which allow fast block transfers, are required for the VMEbus. Tape controllers and event building will be integrated so that events will only be moved once across the VME backplane. Finally, enough video tape drives must be run in parallel to write data at the rate of 8 MB/sec continuously. Offline filtering and reconstruction will be performed on the next generation of ACP processors.

Total DA upgrade cost estimate (spares included)

7000	TDC channels @ \$20 each	\$140,000
700	ADC channels @ \$40 each	\$ 28,000
10	Eurocard Crates @ \$2000 each	\$ 20,000
10	Crate Controllers @ \$2000 each	\$ 20,000
15	SMD Scanner Boards @ \$2500 each	\$ 37,000
12	28 MB FIFO memory buffers @ \$2500 each	\$ 84,000
12	RS-485/VME buffers @ \$3700 each	\$ 44,400
8	CPU/SCSI Controller Cards @ \$4000 each	\$ 32,000
	Tape Drives (not including tapes)	\$115,000
TOTAL		\$520,900

### C. Silicon Microstrip Detector System

We propose to upgrade the acceptance of TPL's spectrometer while improving its redundancy and resolution at the same time. This improvement is important to the experiment in as much as it helps us obtain more charm events, certainly a vastly improved number of events with both charmed particles reconstructed; and it is the only effective way to fully reconstruct beauty events. The better resolution would substantially improve our reconstruction of semi-leptonic events, reduce backgrounds, and allow us to use lower momentum tracks. The importance of these low momentum tracks cannot be understated for finding rare high-multiplicity states which are a major thrust of this experiment.

The present acceptance of TPL is limited by the downstream apertures of our two magnets, M1 and M2, to approximately 100 mrad. We propose increasing this acceptance to between 200 and 250 mrad, improving the redundancy of track finding near the vertex and reducing the track errors at the vertex. We could achieve this by adding ten 100 micron planes to the present system, reconfiguring the present planes and moving the entire system closer to the magnet. The present E769 SMD system (refer to Fig. 1) consists of : two 25 micron strip planes upstream of the target for beam location, two 25 micron strip planes downstream of the target, followed by nine 50 micron strip planes.

To achieve the 200 to 250 mrad acceptance goal, 10 silicon planes (5 cm x 5 cm) are configured as doublets (including the 9 existing 50 micron planes) within 10 cm of the target. Each doublet has strips at 90 degrees to each other, with the orientation of the doublets optimized for track finding efficiency. The doublets are 2 cm apart, starting after the 25 micron downstream planes used in E769. In addition, 5 more doublets of 100 micron strip planes, of a larger transverse dimension (10 cm x 10 cm), will be placed downstream of the 5 cm x 5 cm doublets. The target itself would be 150 cm downstream of its present position, and therefore closer to the drift chamber stations and the magnets.

The only possible disadvantage of moving the target closer to the spectrometer is a degradation of 2-track separation. However, we circumvent this problem by using new 2-hit TDC's on the drift chambers (see DA upgrade section). The limiting factor is then shaping times for pulses from the drift chamber pre-amp cards, which can be clipped, leading to (conservatively) a minimum drift time separation of about 70 ns (0.28 cm).

We are aware that the acceptance upgrade can be further optimized in various ways, such as spacing SMD planes out further, but making them larger in transverse size (this would alleviate space shortage for cables, etc.).

We have studied the effect of the upgrade on the geometric acceptance of single charm, 2-charm, and beauty events as a function of maximum angle ( $\theta$ -max) and of lowest momentum decay track ( $p$ -min) for the most copious decay modes (see Figs. 3, 4 and 5). Changing  $\theta$ -max and  $p$ -min from 133 mrad and 4.0 GeV (E769 values) to 225 mrad and 2.5 GeV (P791 values) leads to typical acceptance increases of 22% for single charm events, 90% for 2-charm events and 50% for beauty events. The upgrade also improves tracking in general. Anyone familiar with the E691 analysis will concede that the "Category-3" tracks contain a lot of background; and they are also numerous enough to cause combinatoric backgrounds in mass plots by themselves. Category-3 tracks are tracks that only went through the silicon (and D1) and D2, but not through D3. Our upgrade ensures that some of the tracks that would have only gone through D2 now go through D3 as well. Further, tracks close to corners of D2 (not fully reconstructed) now go through the main body of that drift chamber. This effectively allows us to use lower momentum tracks in our analysis. In addition, more tracks will go through the Cherenkov counters.

The momentum and angular resolutions of the detector remain essentially unchanged, while the resolution of the projected track position at the vertex improves. This coupled with the larger geometric acceptance ( and background reduction from greater redundancy ) means the silicon upgrade should effectively increase signals by a factor of 2 even for single charm, and of course larger factors for 2-charm and beauty events. The upgrade is expected to cost about \$300K.

#### D. Beamline Upgrade

One expects that the cross sections for heavy flavor production will increase rapidly with beam energy. In particular, by increasing the maximum TPL beam energy from 300 to 500 GeV, we expect a factor of three increase in the beauty cross section and an 80% increase in charm. The added energy also causes a Lorentz boost, which increases the acceptance of the spectrometer for heavy flavor decays. As previously outlined, we intend to add double hit TDC electronics and more planes of silicon microstrips to exploit these Lorentz boosted events.

P791 requires a 2 MHz 500 GeV negative hadron beam. The graph in Fig. 6 plots the E769 secondary beam rate vs a random sampling of run numbers, showing that the apparatus has already functioned at a greater than 2 MHz rate. The proposed beamline combines the preliminary targeting scheme of E769 to produce a zero-degree hadron beam and the secondary beam transport of E691 which maximized the luminosity, upgraded to 500 GeV. Following a preliminary design study for the beamline by Larry Spires, beamline physicist, we believe that the upgrade to 500 GeV requires the addition of two 4-2-240 dipole magnets and a few 3Q120 quadrupole magnets. The new layout will fit within the existing enclosures. In addition, an upgrade for the PS4 sub-station is required. These upgrades are addressed in the existing implementation plan prepared by the Research Division. The cost is estimated to be about \$300K.

Scaling the flux obtained for E769 by the E691 secondary beam transmission, and using curves calculated for the MW beam to scale to 500 GeV, leads to a primary intensity requirement of  $1 \times 10^{12}$  800 GeV protons per 23 second spill.

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#### IV. Rates, Running Time and Schedule

##### Rates

We estimate the charm and beauty yields from the following assumptions:

Beam	500 GeV/c $\pi^-$
Spill Seconds per Run	$2 \times 10^6$
Target	5% interaction length
Charm pairs/interaction	$10^{-3}$
Beauty pairs/interaction	$3 \times 10^{-7}$ (6 nb)
D.A. System Rate Capability	5,000 events/spill second @ 10% deadtime
Low Et Trigger Rejection	$1/6 = .167$
High Et Trigger Rejection	$1/30 = .033$
Charm Particle Trigger, Acceptance, and Reconstruction Efficiency per Produced Charm Event	$.5 \times 10^{-2}$ (based on E691)
Beauty Particle Trigger, Acceptance, Reconstruction Efficiency per Beauty Event	.1%

Experience in E769 indicates that the high Et trigger rate will be 1/5 of the low Et trigger. Taking a 1/10 prescale factor gives the number of low Et trigger recorded events/spill second as:

$$2 \times 10^6 \text{ beams} \times .05 \text{ int rate} \times .9 \text{ live time} \times .167 \times .1 \text{ prescale} = 1500$$

The number of high Et trigger recorded events/spill second is:

$$2 \times 10^6 \text{ beams} \times .05 \text{ int rate} \times .9 \text{ live time} \times .033 = 2970$$

The total, 4470, is consistent with the data acquisition recording rate.

The number of "useful" charm particles per second, i.e. those that will end up as part of a physics result is:

$$2 \times 10^6 \text{ beams} \times .05 \text{ int/beam} \times 10^{-3} \text{ pairs/int} \times .9 \times .1 \times$$

$$.5 \times 10^{-2} \text{ efficiency} = 9 \times 10^{-2} \text{ c particles/spill second}$$

or:  $.9 \times 10^5$  totally reconstructed charm decays

The number of "useful" beauty particles per second is:

$$2 \times 10^6 \text{ beam/sec} \times .05 \text{ int/beam} \times 3 \times 10^{-7} \text{ b pairs/int} \times .9 \times .001 \text{ efficiency} = 2.5 \times 10^{-5} \text{ b particles/spill second}$$

or: 50 totally reconstructed beauty decays

As discussed in the physics section, it may be possible to recognize beauty particles by a D which does not come from the primary vertex and/or high pt electrons which miss the primary vertex, giving an increase in efficiency:

700 partially reconstructed beauty decays

### Schedule and Running Time

Given a prompt approval, we believe that the three major upgrades will be ready in time for a June 1989 run. The  $2 \times 10^6$  spill second run assumed in the section on rates corresponds to 4 calendar months for 100 hour weeks. Adding this to the necessary 2 to 3 month commissioning period and allowing for accelerator and experiment downtime, etc. gives a conservative 7 - 9 month run.

## V. Cost Summary

The new costs for this experiment are summarized here for the three upgrades described earlier.

1.	Beam Upgrade(all new components) (September 18, 1987 estimate by Larry D. Spires)	\$245K - \$350K
2.	Data Acquisition System	\$521K
3.	Upstream Tracking Upgrade (10 planes of SMD's @ \$30K per plane)	\$300K
	Total	\$1066K - \$1171K



## VI. Comparison with Other Experiments

### A. Charm Experiments

To date there have been several groups studying charm production and, in particular, examining  $D^0$ - $D^0$ bar mixing, rare charm decays, and events in which both charms are observed. Table VI.A summarizes these experiments and their status as well as could be determined.

Results from some groups are partial and for others only estimated. Comparing these experiments to the one being proposed it is clear that no other existing experiment provides the statistics required to study the physics in the detail which P791 would allow.

#### $D^0$ - $D^0$ bar Mixing

One experiment has claimed evidence for mixing, others have been able to place upper limits on it. Mark III has reported (1) observation of 3 wrong-sign decays and 162 right-sign decays in a sample of  $D^0$ - $D^0$ bar decays of the  $\psi''$ . This gives an apparent rate of  $3/(2 \cdot 162) = 0.009$ , or:

$$r = 0.9\% \pm 0.5\%$$

The background was estimated to be  $0.4 \pm 0.2$  events from other sources. All three events involved a  $\pi^0$  in addition to the two charged pseudoscalars. Mark III has more recently extended this analysis to include fully reconstructed events containing either a hadronic plus a semileptonic decay, or two semileptonic decays (2). This was motivated by the fact that DCSD's do not contribute in the case of identical final states (3). They found no wrong-sign mixing candidates in either of the semileptonic samples (69 and 12 events respectively). If the 3 wrong sign events are then assumed to be all DCSD's, Mark III quotes  $\rho^2 = 5 \cdot \tan^4(\theta_c)$  with an error of about 60% (2). ( $\rho^2$  is the ratio of DCSD's to right-sign decays in the notation of Bigi and Sanda.)

ARGUS recently published results (4) of a search for  $D^0$ - $D^0$ bar mixing, using cascade decays of the  $D^{*+/-}$  to tag the  $D^0$  or  $D^0$ bar. They found no wrong-sign decays in a sample of 162 events. Their limit is then:

$$r < 1.4\% \text{ at } 90\% \text{ C.L.}$$

E691 performed a more extensive analysis (5) using the same technique on their complete data. Two decay channels were studied:  $D^0 \rightarrow K \pi$  and  $D^0 \rightarrow K \pi \pi \pi$ . This experiment was able to separate the effects of  $D^0$ - $D^0$ bar mixing from DCSD's by studying the effects of lifetime cuts on their data. DCSD's have a decay rate which decreases exponentially, while the box-diagram mixing gives an additional factor of  $t^2$ . They find no evidence for mixing in either mode, and quote a value of  $r = 0.0005 \text{ } ^{+0.0020}_{-0}$  or, as a limit:

$$r < 0.37\% \text{ at } 90\% \text{ C.L.}$$

This result is inconsistent with the value of about 1% suggested by the MARK III results.

P791 can be expected to approach a 90% CL limit on mixing or 0.1%, a value which begins to test theoretical models. The data will also provide a test of the anticipated DCSD rate which would provide an equivalent of 0.3%.

### Rare Decay Modes

Rare decay modes including flavour changing neutral current processes, semi-leptonic, and non-Leptonic Decays can be more fully examined with a higher statistics charm data sample. Also, charmed baryon states could be studied. Mark III has reported the observation of  $D_s^{+} \rightarrow \eta \pi^{+}$  and set a limit on  $D^{+} \rightarrow \mu^{+} \nu_{\mu}$  of  $7.2 \times 10^{-4}$  (6). E691 has examined the decays  $D^0 \rightarrow e^{+} e^{-}$ ,  $\mu^{+} \mu^{-}$ ,  $\mu^{+} e^{-}$  (7) and have measured the rate for  $D^0 \rightarrow K^{-} e^{+} \nu_e$  (8). Also, hadronic branching fractions can be measured more accurately. Current Mark III values are given in several references (9,10,11). Several dozen charmed baryons have been observed by the E400 (12-15) and CLEO (16) groups. With an order of magnitude more charm decays than E691 and E769, P791 would significantly enhance our knowledge of all of these topics.

### Double Charm Events

Currently, only a small number of events in which both charms are observed have been recorded. Of these events, many are not fully reconstructible and one of the charmed particles is only tagged. Although the total number of charm pairs is large for Mark III, their sample of totally reconstructed pairs is very small (10). Emulsion and bubble chamber experiments report less than a hundred total charm pairs. Completely reconstructed events number in the dozens (18,19). E691 claims to have on the order of 100 fully reconstructible charm pair events (20). The proposed experiment would significantly enhance this sector of study.

### Other Comparisons

Various schemes for triggering have been examined by different groups. The use of an Impact parameter trigger employed by WA82 was expected to provide a rejection factor of about 50, but has since proven to be less effective, although final results are not complete (21). The reliability of an Et trigger has been demonstrated by E691 and E769 and gives a charm enrichment factor of 3 over interaction triggers.

A large number of groups anticipate future running to accumulate higher charm statistics, though it is difficult to cover them exhaustively. The preliminary data reported here for WA82 was for only the first of two runs and, with further improvements to their beam, trigger and vertexing, they may accumulate a large charm sample in the next CERN running period. Experiment WA84, also employing the OMEGA spectrometer, was tested during the last running period at CERN and will run again. Although E687 was limited by the fire during the last run, they have indicated that they intend to increase their photon beam energy and make the modifications necessary to also obtain a very high statistics charm sample. In the more distant future SELEX, which would employ a Hyperon beam, might effectively produce charmed baryon states (22).

## B. Beauty Experiments

Two fixed target experiments at CERN have observed beauty events. WA75 observed one  $B^- B^0$  pair in emulsion (1), and WA78 obtained 13 trimuon events from  $\pi^-$  uranium collisions, with a beam energy of 320 GeV (2). This second experiment obtains a cross section for  $b\text{-}\bar{b}$  pairs of  $(4.5 \pm 1.4 \pm 1.4)$  nb/nucleon, higher than the perturbative QCD prediction of 0.7 to 2.0 nb. The analysis of dimuon events from WA78 yielded 29 positive muon pairs and 35 negative muon pairs (3). Combining these three data samples gives a cross section of  $(2.0 \pm 0.3 \pm 0.9)$  nb per nucleon. The UA1 measurement of the  $p\bar{p} \rightarrow b\bar{b} X$  cross section  $(1.1 \pm 0.1 \pm 0.4 \text{ micro-b})$  is in good agreement with the ISAJET prediction of 1.7 micro-b (4).

There are several sources of uncertainty in these cross section calculations. Especially at lower values of  $\sqrt{s}$ , the relative contributions of perturbative and non-perturbative QCD terms is not known. Also, the contributions from terms of order higher than  $\alpha(s)^2$  have not been completely calculated. Additional inputs to the calculation which contribute to the uncertainty of the cross section are the mass of the  $b$ -quark, the  $Q^2$  evolution scale for  $\alpha(s)^2$ , the gluon and quark structure functions, and  $A$ -dependence. A good measurement of the  $b\bar{b}$  cross section is essential for the future development of both fixed target and collider beauty experiments.

We will isolate events containing beauty by selecting  $D$  events that have evidence that the  $D$  is from  $B$  decay. Two useful tags will be the mass difference between the  $B$  and  $D$  in the event, and the location of the  $D$  vertex. Since the branching ratio for  $B \rightarrow D$  is nearly 100%, the branching ratio \* acceptance for such events will be similar to the branching ratio \* acceptance for  $D$  events. Using the cross section calculations of Berger (5), we expect to partially reconstruct 500  $B$  events during the experiment. Additional inefficiencies will enter and we project only 60 fully reconstructed beauty decays in phase I. Table VI.B summarizes these expected yields and those for other experiments and proposals with the information coming largely from Garbincius (6) or, using similar assumptions about the cross section and running periods.

This is a conservative approach to studying beauty physics with fixed target experiments. The major upgrade, the DA system, is a logical extension of the proven and successful system used in E769. Once this new system is running, then the maximum number of events with beauty will be recorded on tape in a given running period. During the offline analysis, various filters will be applied to obtain the optimal signal to noise ratio in each channel. The results of this experiment will guide future efforts by studying the effectiveness of various data filters, and by measuring the beauty cross section.

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Table VI.A Comparison of Charm Experiments

Experiment (ref.)	Beam	Target	Vertexing -Trigger	Trigs	Total Charm	Mixing	Rare BR	Charm pairs ( )=fully reconstr.
NA27 LEBC-EHS (19)	360 GeV/c Pi-	LH2	Bubble Ch.	265K	114			53(12)
NA27 LEBC-EHS (23)	400 GeV/c p	LH2	Bubble Ch.	1M *	134			
E743 LEBC-MPS (24)	800 GeV/c p	LH2	Bubble Ch.	500K *	82	----with 40% of film analysed----		
NA32a (25)	200 GeV/c pi-, K-, p	Si	Si-Interact	40M	200			
NA32b (25)	230 GeV/c pi-, K-	Si+CCD	Si-K+K- K+ p+	17M	85 Lambda c 530 D	----with 75% of data analysed----		
WA58 (18)	20-70 GeV Gamma	Emulsion	Emulsion	17K	45			36
MARK III (2, 9, 10, 11)	e+e-	Psi(1370)	No vertexing	48K	27.7K D0D0 20.3K D+D-	.01 **		(~400)
ARGUS (4)	e+e-	Upsilon(2S) Upsilon(4S)	No vertexing			<.014		(162)
CLEO (16)	e+e-	Upsilon(4S)	No vertexing		1600 D0, 1600 D+ 1250 D++, 385 D*0 62 Ds, 160 Lambda c 24 --- With 80% of electronic data analysed			
E653	800 GeV/c p 600 GeV/c Pi+	Emulsion	Si-Muon	6M 9M				
E691 (5, 7, 8, 20)	av. 150 GeV Gamma	Be	Si-Et	100M	12K	<.0050 ***		(~100)
E400 (12-15)	600 GeV neutron	W, Si, Be	MWPC-Interact	45M	60 Cas.c+ 74 Sig.c++ 58 Sig.c 0		D0-->K0K0	
E887 (1987 data)	av. 210 GeV Gamma	Be, Si	Si	70M	4K (Est.)	----	Not analyzed	----
E887 (Next run)	av. 250 GeV Gamma	Be, Si	Si	500M	50K (Est.)	----	Projected	----
E769	250 GeV/c p, K, pi (+, -)	W, Cu, Al, Be	Si-Et	500M	6K (Est.)	----	Not analyzed	----
WA82 (21)	340 GeV/c Pi-	W, Si	Si-Imp.par.	10M	2K (Est.)	--Projection from 5% of data from 1st run		----
WA82 (Next Run)	340 GeV/c Pi-	W, Si	Si-Imp.par.	10M	10K	---- Projected		----
P791	500 GeV/c Pi-	W	Si-Et	10G	100K	---- Projected		(~2000)

\* These represent triggers in the fiducial volume of the bubble chamber.

\*\* Limits set by Mark III on particular rare decay modes (6):

D+ --&gt; Eta Pi+

Observed

\*\*\* Limits set by E691 on particular rare decay modes (7, 8):

D0 --&gt; e+ e-

&lt; 8E-5

&lt; 8E-5

D+ --&gt; Mu+ Neumu

&lt; 7.2e-4

D0 --&gt; Mu+ Mu-

&lt; 1E-4

D+ --&gt; Pi+ Mu e

&lt; 2E-4

Table VI.B Comparison of Beauty Experiments\*

Experiment (status)	Beam	Target	Vertexing -Trigger	Trigs	Total B Production	Anticipated B Yield	Measured B Yield
WA75 (Ref.1)	350 GeV/c Pi-	Emulsion	Emulsion-Muon	1.5M			1
WA78 (Ref.2)	320 GeV/c Pi-	U	-Muon, E missing	22M			13 (3 mu)
E653 (1985 data)	800 GeV/c p+	Emulsion	Emulsion, Si	6M		5	
E653 (1987 data)	600 GeV/c Pi-	Emulsion	Emulsion, Si	9M		14	
WA82 (1987 data)	340 GeV/c Pi-	W, Si	Si-Imp. par.	10M	1500	50-100	
WA84 SCIFI (1987 test, next run)	360 GeV/c Pi-	SCIntilating Fibers	Si-Interact.	15M	670	200-300	
E771 (next run)	800 GeV/c p	W	Si-DiMuon			540	
E706/E672 (1987 data)	530 GeV/c Pi-, p	C, Be	Si-DiMuon		6K Psi's	6	
E706/E672 (next run)	530 GeV/c Pi-, p	C, Be	Si-DiMuon		200K Psi's	200	
E690 (next run)	800 GeV/c p	H	PWC- Track Mult.		700K **	No estimate	
P789 (next run)	800 GeV/c p		Si-Lifetime			1000s	
P791 (next run)	500 GeV/c Pi-	W	Si-Et	10G	50K	500 part. reconstruct 60 full reconstruct	
E687	av. 250 GeV Gamma	Be/Si	Si- Hadronic Energy	2.5M	2.5K	3-30	
P786 (next run)	750 GeV/c Muon	LH2/LD2	Streamer Ch.- Tri Muon		100K	1000 Mu-Mu- X	

\* Most of the information for this table is from reference (6).

\*\* Bs from Target fragments produced diffractively.

## VII. PROPOSAL SUMMARY AND REQUESTED APPROVAL

P-791 is a proposal to continue the Laboratory's successful series of heavy flavor experiments. Based on the experience of the previous experiments at TPL, modest upgrades to the apparatus and a new data acquisition system have been proposed. These improvements, in conjunction with the beamline upgrade, offer an order of magnitude more data in the hands of a group whose efficient off-line analysis has led to significant and prompt publications. The requested approval at this time is required for the June 1989 Fixed-Target run.

Similarly the streamer chamber technique, proposed as part of the running in the next Fixed-Target period, has great potential. It is the only triggerable, high resolution,  $4\pi$  device which has a chance of contributing to beauty physics. We request the opportunity to demonstrate this potential in charm physics now.

# TAGGED PHOTON SPECTROMETER E769

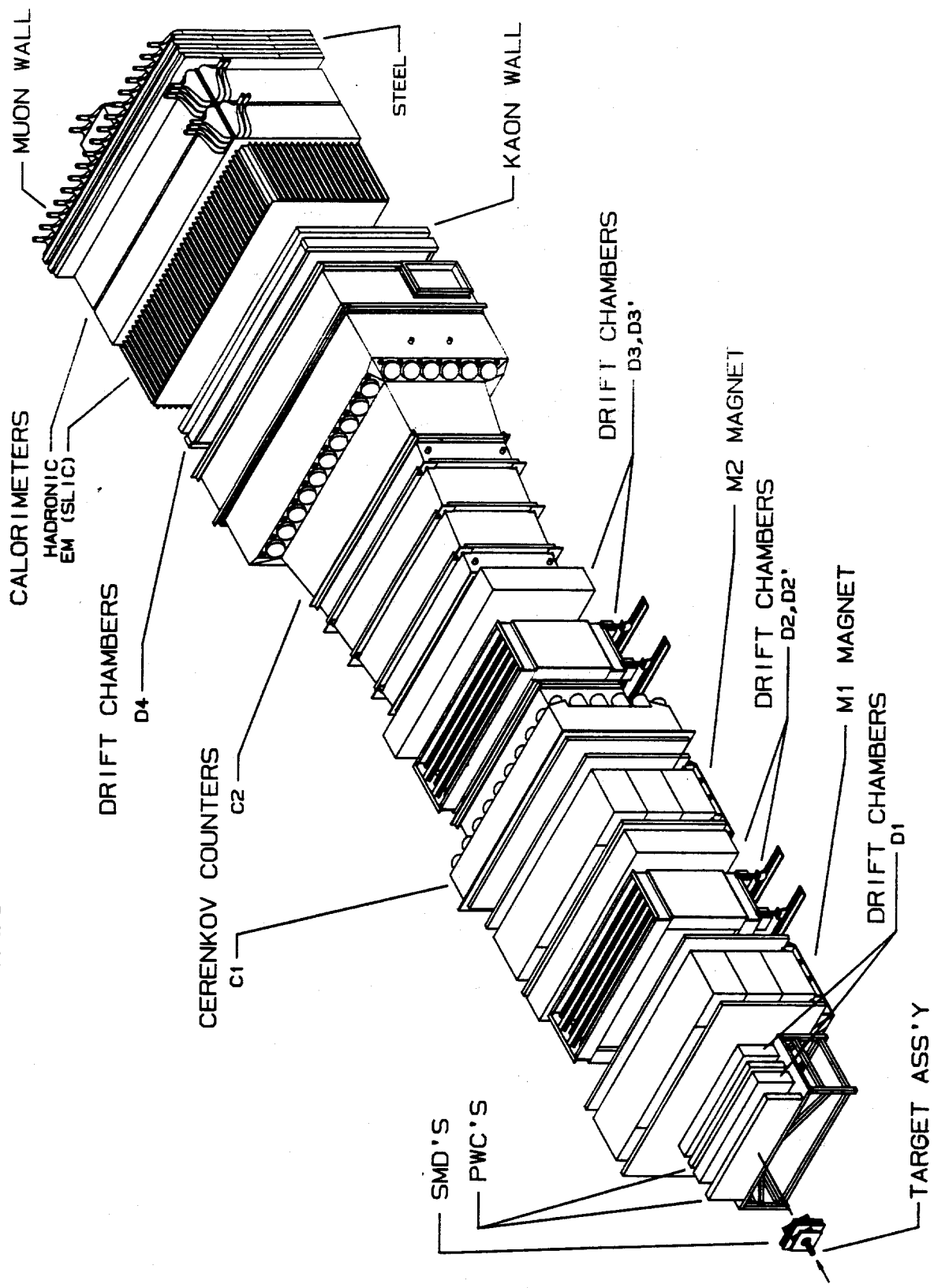


Fig. 1



# P791 5000 EVENT/SPILL-SEC DA

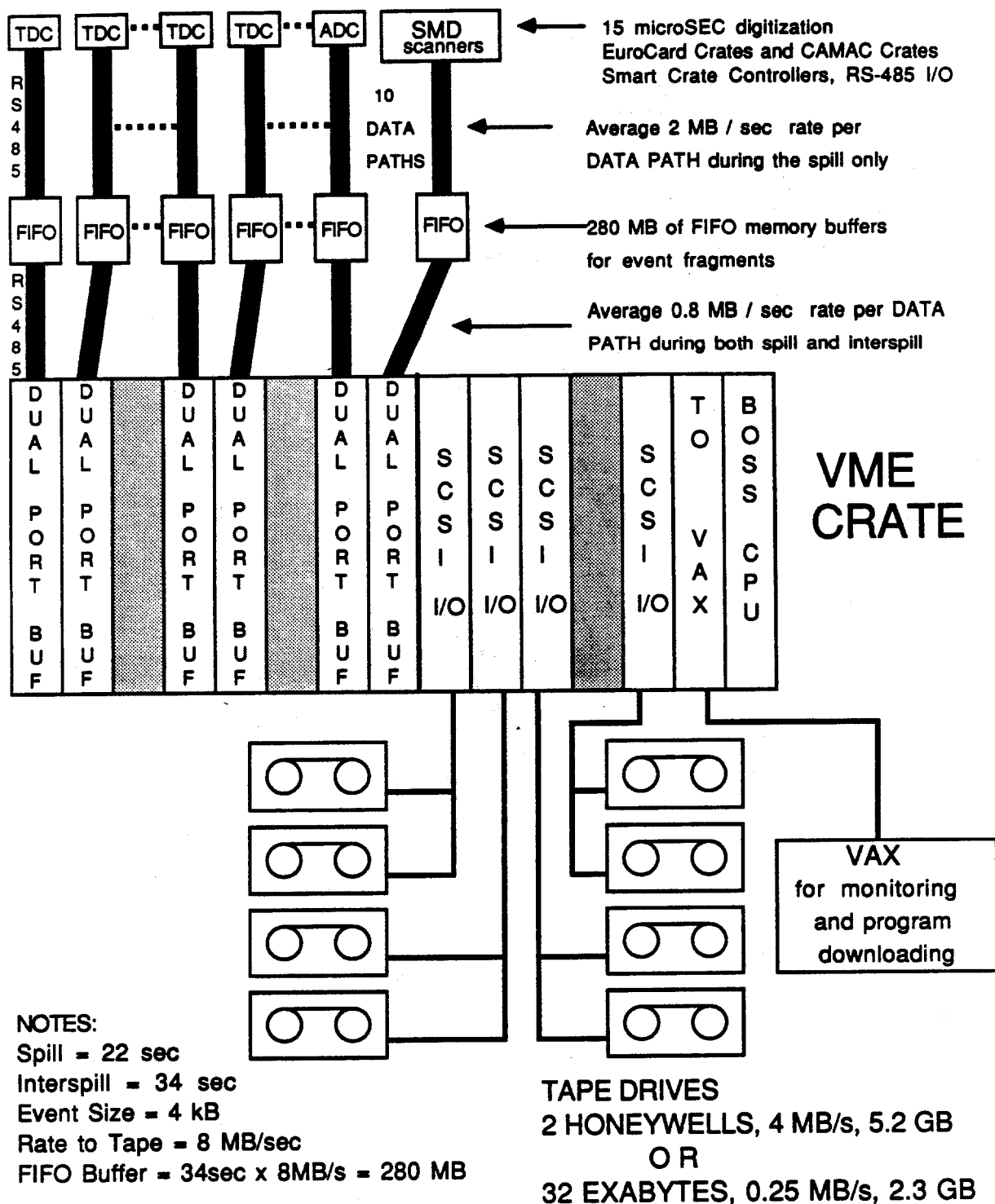


Figure 2

E791 CHARM PI-BEAM  
 THETA ACCEPTANCE  $D^{+-} \rightarrow K \pi \pi$

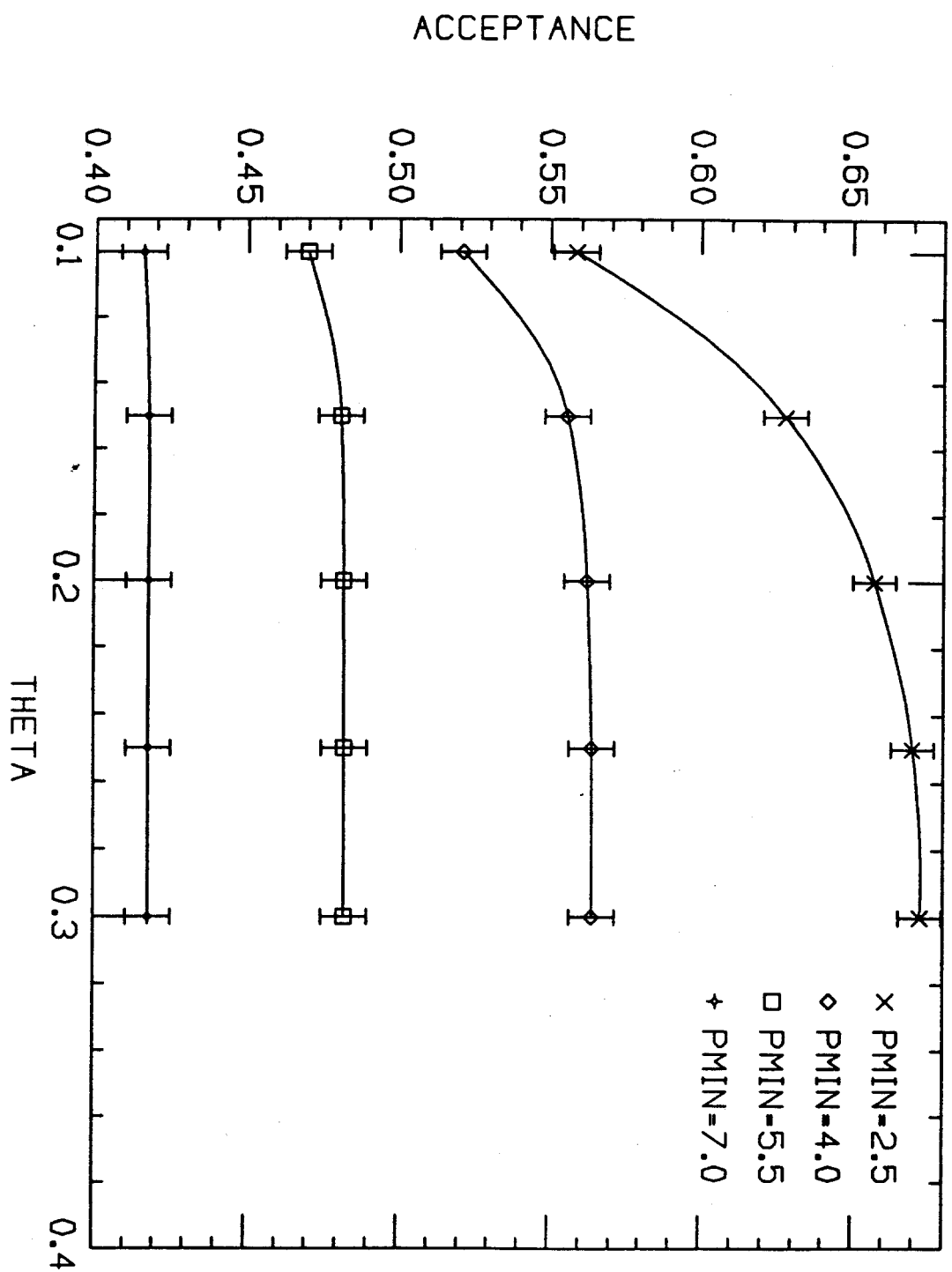


Fig. 3

E791 CHARM PI-BEAM  
THETA ACCEPTANCE FULL EVENT

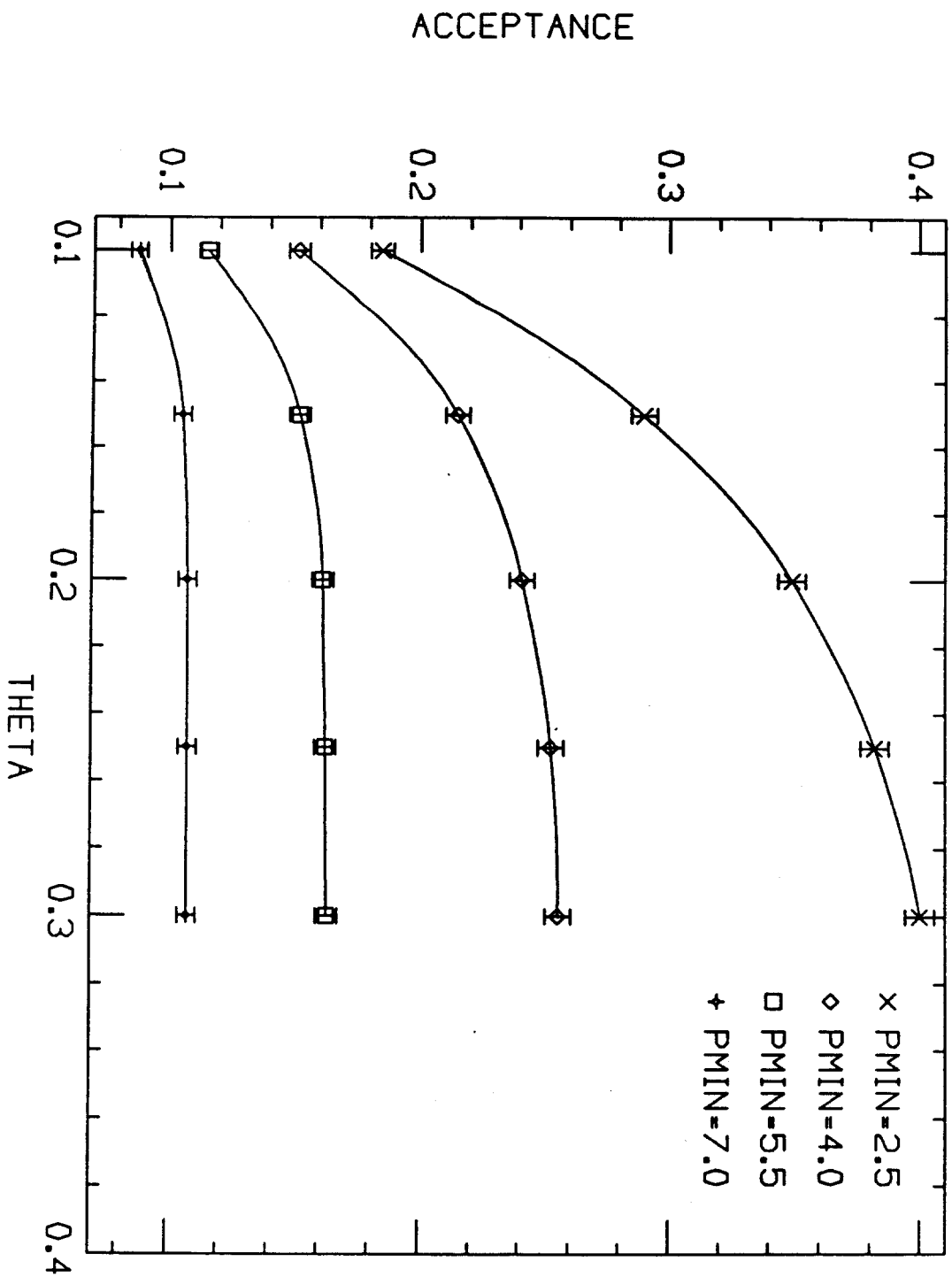


Fig. 4

# E791 BEAUTY PI- BEAM

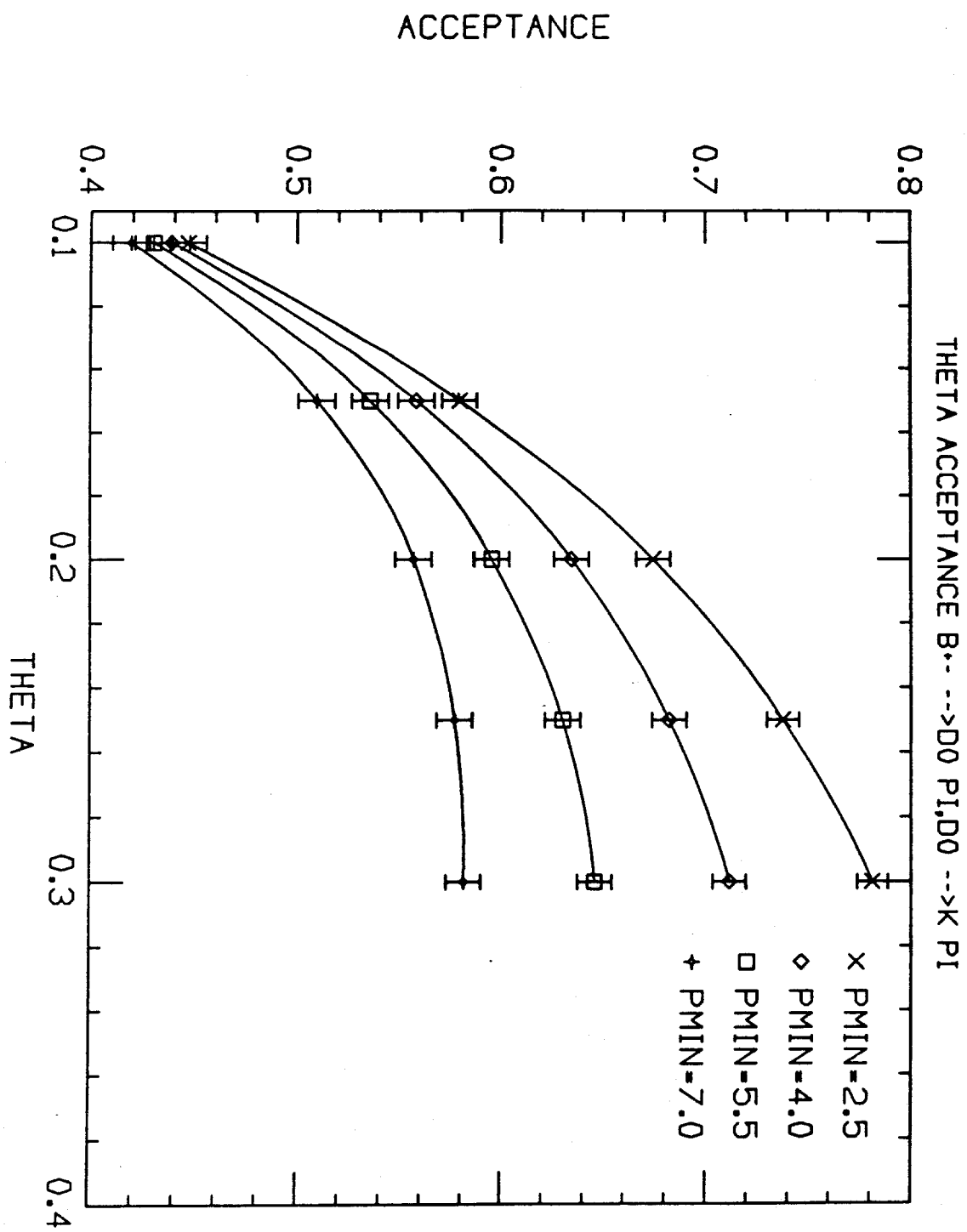


Fig.5

# SECONDARY BEAM RATE (MHZ)

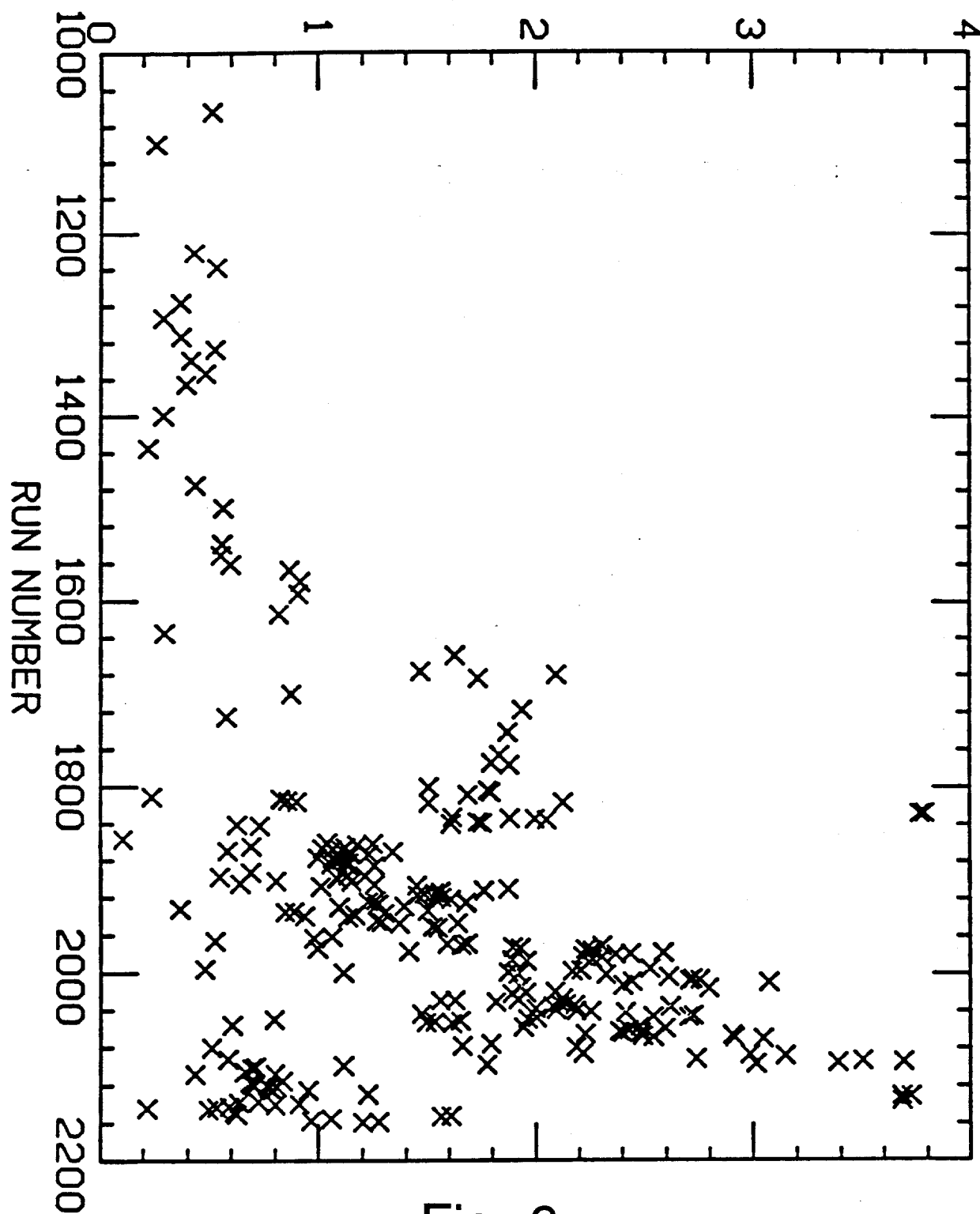


Fig. 6

## Appendix

### Charm Physics with the Yale-Fermilab High Resolution Streamer Chamber in the TPL Spectrometer

#### Outline

- I. Overview
- II. Physics Goals
- III. Characteristics of the Streamer Chamber in TPL
- IV. Streamer Chamber Status
- V. Film Analysis
- VI. Fiducial Volume Trigger
- VII. Schedule and Running Time
- VIII. Costs

#### I. Overview

We propose to operate the streamer chamber simultaneously with a part of the P-791 running. The chamber would serve as an "active" target in the spectrometer. The special properties of the chamber as a detector -  $4\pi$  acceptance, excellent pattern recognition, and high accuracy - would allow the study of aspects of charm physics which are complementary to goals of the purely electronic part of P-791.

We will use a simple trigger consisting of a fiducial volume "finder" in conjunction with the global transverse energy trigger used in E-691 and E-769. We propose to take  $3 \times 10^6$  pictures which will contain 9000 or more charm events.

#### II. Physics Goals

We start by giving the charm rates we expect. The simple trigger (low  $E_t$  + FV) has a very high rate in MHz beams. Therefore the chamber will run at a rate we determine by setting the chamber re-fire deadtime. At any reasonable rate (e.g. 1 to 10 Hz) we can take many millions of pictures. The result is that an interesting number of charm

events plus the off-line analysis effort determine the reasonable number of pictures. Running at 5 hz for 150 spill-hours gives 3 million pictures at a film cost of \$56K.

Assuming that the fraction of charm production to all inelastics in 500 GeV  $\pi^-$ -nucleon collisions is  $10^{-5}$  and (as shown by E-769) that the low  $E_t$  trigger enhances charm by a factor of 3, we expect one charm event in every 333 pictures. This yields 9000 charm events or 18,000 charm decays.

We also note that the fiducial volume trigger can be set for a rather short fiducial volume so that every event is optimally located in the chamber for the best resolution.

With this sample we can address the following physics:

1. Measurement of inclusive charged and neutral D meson production cross sections over the full range of Feynman  $x$  and  $P_t$ . The topology distinguishes between  $D^0$  and  $D^+/D^-$  and the lifetime (via miss distance) allows the separation of  $D^+/D^-$  from  $D$  and  $\Lambda_c$ . Note that these measurements are independent of decay mode. The use of the miss distance distributions to measure lifetimes is discussed in section III.

Note also that negative regions of  $x$  are studied as well as positive  $x$ . This could, for example, be important in looking for leading charmed baryon production in  $\pi$ -nucleon collisions where the "leading" baryon is presumably backward in the center of mass. We note that, even for those events whose tracks miss the spectrometer, the topology (production angle, decay length) gives information on a statistical basis about the production kinematics. Of course, maximum use will be made of the tracks which do go through the spectrometer.

2. Measurement of the correlations between the two D's on an event by event basis: again topology and lifetime allow these measurements to be done over the full  $x$  and  $P_t$  range independent of branching ratios.
3. Measurement of the production cross sections for  $D_s$  and  $\Lambda_c$ : this can be done from the lifetime curve of charged decays. This measurement is possible (or more precisely, we know that it is possible) because of the recent result of E691 on the  $D_s$  lifetime.

The best lifetimes of the relevant particles are from E-691<sup>2</sup> as listed below :

$D^+/D^-$	1.09	$+(-).03$	$+(-).025$	ps
$D_s$	.47	$+(-).04$	$+(-).02$	ps
$\Lambda_c^s$	.22	$+(-).03$	$+(-).02$	ps

The three lifetimes are almost perfectly "chosen" for a decomposition of the decay curve. Estimates indicate that a measurement of the  $D_s$  cross section to the ~15% level is possible if  $D_s$  is produced at 10% of  $D^+/D^-$  and  $D^+/D^-$  is 1/4 of charm. Clearly full Monte Carlo studies are in order and are being done.

### III. Distinguishing Characteristics of the Streamer Chamber in TPL

The chamber has three properties which are important for the complementary physics we propose to study.

1) Very good acceptance, essentially  $4\pi$  in the center of mass.

2) Excellent pattern recognition. We will have a negligible false track rate. There are on the average at least 150 measured points on each track. There will of course be some tracks (very few) which are overlaid by other tracks, however we will see this and exclude them from the analysis. There is also the ability to "see" in as close to the vertex, for each track, as is allowed by track overlaps. Thus, measurements on low energy wide angle tracks begin closer to the vertex than small angle higher energy tracks. Given a  $< 15$  micron demonstrated per point setting error we expect a  $< 50$  micron 2 track resolution. This corresponds to resolving 2 tracks at 2.5 mr by 2 cm. Because of the restricted fiducial region in the charm experiment, tracks will range from 8 - 10 cm long.

3) Excellent resolution. Although we have not analysed our best data from the T-755 run yet, the older 40 atmosphere data already give demonstrated streamer setting errors and densities, 15 micron streamer setting error and 1 measured streamer per mm, which would give an impact parameter resolution of 5 microns or less. We have other data, not yet completely analyzed, which clearly have greater streamer densities.

The consequences of these characteristics are as follows:

a) 1 prong decays will be useful.

b) The vertexing error will not be degraded for the low energy tracks because we will either see the vertex directly or, if the vertex is determined by pointback, the extrapolation distance will be compensatingly less for low energy (and wider angle) tracks.



c) We measure particle lifetimes from impact parameter (primary vertex miss distance) distributions. We recall that the miss distance distribution measures the lifetime with almost the same power as the direct measurement of the proper time distribution. Monte Carlo studies (done for P-755) as well as an analytic study<sup>3</sup> show that the result of a lifetime determination from a sample of miss distances has a standard deviation 10% larger than a determination from a sample (of the same size) of proper times.

d) Both charms in the event can be detected in almost all cases. We also note that a large fraction of the charm particles observed in the chamber will send their charged tracks through the TPL spectrometer. This sample will allow important checks to be done on the purely topological analysis. Incidentally, in essentially every event some tracks will go through the spectrometer and will be useful in the analysis.

e) The interplay between the spectrometer and the chamber data will also aid in all studies. We will know which tracks did and did not come from the charmed particle decays and the primary vertex. This can be important in physics studies where signals are low and there are significant backgrounds. Recall again that the chamber assignments of track provenance are independent of decay interpretation.

#### IV. Streamer Chamber Status

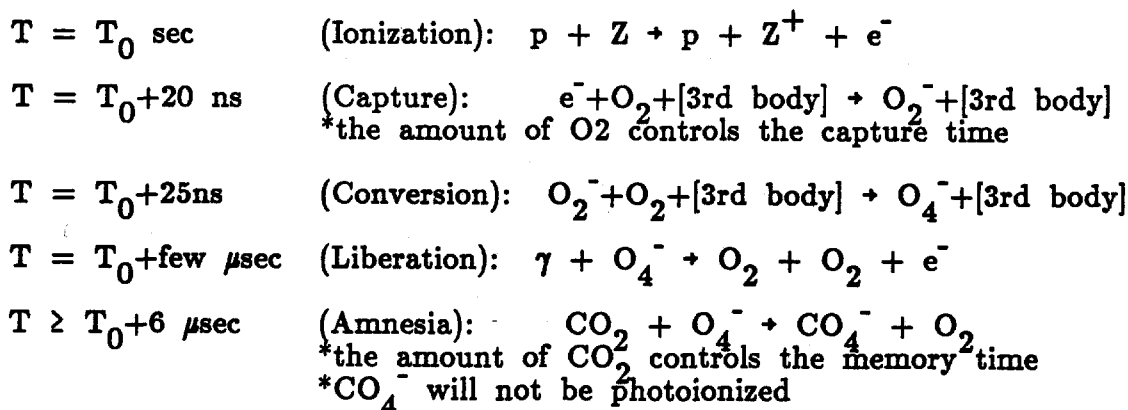
Traditional streamer chambers operate near 1 atm. with streamer diameters in the 1 mm range. Such conditions are not suitable for studying charm or beauty, since at Tevatron energies these particles will only travel a few mm before decaying.

In 1982, the Yale/Fermilab group began to develop a streamer chamber with much improved resolution. The first generation chamber had exploited higher gas pressures. The streamer size scales as  $1/\text{pressure}$ , while the thermal diffusion of the ionization electrons goes as  $1/\sqrt{\text{pressure}}$ . There is then a pressure beyond which diffusion dominates in track resolution. In a 60 atm. chamber,  $\sigma = \sqrt{t} \mu\text{m}$ , where  $t$  is the trigger delay in  $\mu\text{sec}$  (the time between the initial ionization and the H.V. pulse). For a few  $\mu\text{sec}$  delay, this leads to tracks in the 200-300  $\mu\text{m}$  (full width) range. This was the type of chamber used in the E-630 charm experiment at Fermilab.

To realize the full potential of vertex detection of charm and beauty, track widths of 50  $\mu\text{m}$  or less are needed. This corresponds to 15  $\mu\text{m}$  standard deviations for the diffusion of individual streamers. The second generation diffusion suppressed chamber was developed with this goal in mind. The scheme is:

1. Store the initial ionization electrons on an electronegative gas in the form of massive negative ions. The thermal diffusion during the few usec trigger decision is virtually eliminated.
2. Liberate the electrons with a photoionization laser just before the H.V. pulse arrives to form streamers.
3. Build in a memory time by adding a gas which will "steal" the electrons after a suitable trigger delay time. This new species of negative ion should have a negligible photoionization cross section so that subsequent triggers will not integrate old information.

In our chamber we use  $O_2$  to store track information and trace amounts of  $CO_2$  to limit the memory time. The chemistry is:



This scheme was shown to work in preliminary investigations at Yale prior to 1987, and then extensive tests were performed in the Meson Test Beam at Fermilab during the 1987-88 fixed target run (T-755).

Figures A-1 and A-2 show a block diagram and a sketch of the setup tested at Fermilab. Below is a list of the characteristics of the streamer chamber as used in T755.

chamber volume	13.5 cm x 4 cm x 8 mm
gas	up to 60 atm. Ne/He (90%/10%) ~4 psi $O_2$ , ~10 $\mu\text{m}$ Hg $CO_2$
electron capture time	~40 ns
chamber memory time	5-10 $\mu\text{sec}$ (adjustable)

The following is a list of preliminary results of the chamber's performance from T755. All the data was taken at 40 atm.

streamer diameter	50-150 $\mu\text{m}$
$\sigma$ (diffusion)	15 $\mu\text{m}$
visible streamer density	2-4 str/mm
density of measured streamers	1-2 str/mm

We recently digitized some film using an EGG Reticon photodiode array in the Film Analysis Facility (FAF) at Fermilab (numbers in the above table derived from film digitized by humans). Preliminary results are encouraging. One track was measured both by hand and by the diode array. The track was found to have a diffusion standard deviation of  $13.3\text{ }\mu\text{m}$  by hand, and  $23\text{ }\mu\text{m}$  by the diode array. The diode measured about twice as many streamers as the hand measurement, some of which were very large and should not have been included (like delta rays, for example). Improvements in the measuring algorithm should improve the results. The diode array looks quite promising for resolving two nearby tracks. While a human would see overlapping streamers as one entity, the diode array, using proper pulse height cuts, seemed to distinguish the overlapping streamers. Studies using the diode array will be actively pursued in the coming months. Throughout our association with FAF, Jim Hanlon and his staff of scanners and technicians have consistently provided their support and expertise for which we are grateful.

One potential problem encountered during the T-755 run was a beam-induced streamer background. We are confident that this is not the photoionization of  $\text{CO}_4^-$ , since a drift field applied to the chamber does not sweep out the contaminant (our drift field would sweep out  $\text{CO}_4^-$ ). We feel it is likely due to the particle beam causing outgassing from our electrodes. (The minimum spot size is the test beam was such that the beam struck both electrodes when centered on the chamber.) The contaminants are then photoionized and seen as background streamers on film. This situation was remedied simply by shutting off the gas flow through the chamber during the beam spill. The laser then cleaned contaminants faster than they were produced. There was concern that at beam rates of 2 MHz this scheme would not work (the maximum Mtest beam intensities were typically 20 kHz). However, since the contaminants seemed to be long-lived, we could integrate the meager Mtest beam over a period of several seconds and get within a factor of 3 of the P791 beam rates that we would integrate between triggers. The background was not visible during these tests, so we expect to withstand beam rates of P791 without background. An additional laser pulse between triggers could also be used to assist in the cleaning process if necessary.

Some upgrades need to be made on the chamber before final installation in TPL.

- The present gap of 8 mm between electrodes will be increased to 2 cm. This means a new Marx generator, capable of 750-900 kV, must be purchased.
- The timing jitter between the photoionization pulse and the high voltage pulse is about 30 ns. We hope to run in P791 with a capture time of 20 ns (about 6 psi  $\text{O}_2$ ), so the jitter

should be reduced to about 5 ns. To achieve this we will laser trigger the Blumlein pulser.

A new imaging system will be needed. The chamber is presently being imaged (the lens is borrowed from LEBC) on to the face of an image intensifier tube. In order to obtain the necessary resolution, we may have to split the image over two tubes. We would then recombine the tube outputs with fiber optics so that both will fit on 35 mm film, allowing us to operate the camera with a single pull down per frame advance. A camera used at SLAC is available (the advance time is 68 msec) and can be modified for our use. We are also investigating various image tubes and image dissectors.

## V. Film Analysis

In this section we discuss our plans for analysis of the 3 million pictures taken during the streamer chamber run. In summary, we plan to fully digitize ALL the pictures, then enrich the sample by a combination of scanning and cuts based on the spectrometer data, and then fully measure the charm subset.

We note that one of the major strengths of the streamer chamber technique is the  $4\pi$  acceptance of the chamber. This important advantage would be lost if we only measured tracks or events which are totally reconstructed in the downstream spectrometer. As we discussed earlier, there are numerous physics measurements that can be made without requiring full reconstruction of the tracks or events.

Below we demonstrate that we can fully digitize all the pictures, and select and fully measure the charm subset using current technology in a reasonable amount of time.

Note that by digitization we mean transformation of the film record into a computer record, without pattern recognition or streamer or track measurement. By measurement we mean location and measurement of streamers on tracks, and fitting of the measured points into tracks.

We have used with success the linear diode array digitization system developed by L. Voyvodic and collaborators at Fermilab. We have digitized a number of streamer chamber pictures, and base many of our estimates on our experience with the MOMM's at FAF.

Starting with  $3 \times 10^6$  pictures, a digitization pixel size of  $20 \times 20 \mu\text{m}^2$  (well matched to our expected streamer size), a chamber area of  $135 \times 40 \text{ mm}^2$ , and an 8 bit grey scale gives 13.5 Mbyte/picture. We expect zero suppression and data compaction will reduce the data by an order of magnitude, giving 1.35 Mbyte/picture.

Total storage for  $3 \times 10^6$  pictures is  $4.1 \times 10^{12}$  bytes. A Honeywell VLDS tape holds  $5.9 \times 10^9$  bytes, so we can store all the pictures on less than 700 tapes (note: a tape costs approximately \$11.00). One tape drive can easily service several digitizers.

We estimate we need approximately 10 sec to digitize a picture, giving  $3 \times 10^7$  seconds digitizing time for the entire experiment. With 2 digitizers this requires approximately 1/2 year.

A very important part of the event analysis will be selection of the 9000 charm events from the full 3 million event sample. We plan to accomplish this using a computer aided human scanning (recall that at this stage, events are fully digitized and available to a workstation). The computer will display the event to a scanner on a screen using a transformation which magnifies the primary vertex region, expands the angular scale, but where straight lines remain straight (Dreverman transformation). In this coordinate system tracks which miss the primary vertex are easy to detect visually. The scanner should be able to rapidly reject events which have no decay vertices, and flag the events which might have.

Allowing 1 minute to accept or reject an event, and 6 scanners in 3 shifts gives 7500 hours or slightly less than a year to scan the entire data sample. Note that this phase of the analysis can be done in parallel with the digitizing effort.

The charm subsample identified through the preceding analysis will then be fully measured by computer aided human measurers. The human will define regions of the picture containing single tracks in which the computer will find and measure streamers, and then fit them to tracks. Simulations using monte carlo events displayed on a Macintosh computer with a mouse indicate that a measurer can rapidly define roads or regions of the pictures containing single tracks. Allowing 5 minutes/event to measure gives 1700 hours needed to fully measure the charm sample (10000 events, including background). Two scanners working 3 shifts/day can measure the entire charm sample in less than a month. Again this phase can proceed in parallel with the previous ones.

The detailed analysis methodology is under development via our analysis of T755. Exact cost estimates will depend on the final system. However, we note that suitable diode cameras cost ~\$5000, the Honeywell tape drive is about \$45,000, and suitable workstations are becoming readily available.

We have demonstrated above that digitization and scanning of the full data sample, and measurement of the full charm subset is feasible using current technology in a reasonable amount of time. We are vigorously investigating developments and techniques used in the field of pattern recognition and automated measurement, and hope to further simplify and automate the procedures outlined above.

## VI. Fiducial Volume Trigger

The fiducial region trigger will use tracking detectors immediately downstream of the streamer chamber to define interactions occurring in the fiducial region of the chamber. These detectors could be PWC's with 1 mm or less wire spacing, however slightly higher resolution would be useful. The very high resolution of silicon micro-strip detectors is better than required but could be used. We are currently investigating the use of plastic scintillating fibers of about 200  $\mu\text{m}$  size transverse to the beam. Such fibers and the required readout are under development for LEP-3<sup>4</sup>. For the purposes of discussing a trigger design, we will assume a detector with 200  $\mu\text{m}$  granularity covering the desired region. The design given below can easily be adapted to other configurations.

Figure A-3 shows the geometry involved. We need only one coordinate for this trigger. We envision either splitting or masking the detector readout so as to ignore the central region. With the geometry and resolution indicated, tracks with angles less than 20mr give little information on the vertex location. The trigger is simplified if the beam is narrow in the direction measured by the tracking detector ( $< 1\text{ mm}$ ) but a tagging hodoscope in the beam just upstream of the streamer chamber will allow a wider beam. Further Monte Carlo and data studies will indicate just what angular region needs to be covered downstream of the streamer chamber. We assume that the readout of the tracking detector planes proceeds simultaneously from both ends towards the center region (which as stated above is ignored). An angular region large enough to guarantee the presence of a few tracks is covered by the readout. This scheme naturally splits the processing task into two halves.

The processors must identify tracks (aligned hits in the three planes within a tolerance) and require that the tracks intercept the beam track inside the fiducial region (within tolerances). Finding a sufficient number of such tracks will produce a trigger.

Figure A-4 shows a block diagram of the processor. As indicated above two such units (one for each half of the tracking planes) would be used. Since the central region of the planes is ignored and only half a plane is covered by the processor, the multiplicity of hits that must be accommodated is modest. Further, since readout is started at the outer edges of the planes, the processor is most likely to acquire the largest angle tracks which will have the best vertex resolution. We show a processor capable of handling up to 4 hits per half plane. The processor can of course be expanded if further Monte Carlo and studies of the data indicated this is required.

We assume the hits in the plane are encoded rapidly (about 50 - 100 ns per hit is adequate) and passed serially to the processor. Since we

are dealing with a modest number of hits, the parallelism required here is modest. We assume all hits from one plane (Y1) are handled in parallel (4 processing cells) while the hits in the other planes are cycled through the processor ( $4 \times 4 = 16$  cycles). The beam tagging hit (if required) is also passed to the processor. At this point the processor must cycle through all hit combinations in the two downstream planes (Y2 and Y3) to find good tracks and good track intercepts with the beam particle. Figure A-5 shows a processing cell for solving these two problems.

A good track is defined by:

$$| (y1+y3)/2 - y2 | < \text{err}$$

where the lower case letters refer to the actual hit coordinates and "err" is the allowed tolerance. We have assumed the planes will be equally spaced along the beam direction. This equation may be written as:

$$-\text{err} < (y1+y3)/2 - y2 < \text{err}$$

or

$$0 < (y1+y3)/2 - y2 + \text{err} < 2 \times \text{err}$$

This computation is accomplished by a double adder plus a comparator.

To find the intercept of the track with the beam particle (in the beam direction - or Z as indicated in fig. A-3) one may write the track equation as:

$$Z = aY + b$$

One needs to find the intercept "b". Writing the solution in terms of the longitudinal locations of the planes (Z1 and Z3 in fig. A-3) and the track hits in the planes (y1 and y3) one has:

$$b = Z1 - (Z3-Z1)x(y1/(y3-y1))$$

If a beam tagging coordinate (yB) is used, this equation becomes:

$$b = Z1 - (Z3-Z1)x((y1-yB)/(y3-y1))$$

The two coordinate differences are computed in parallel and the results passed to a memory look up unit (MLU) to find the intercept. One need not derive the intercept in the MLU since the desired "answer" is only whether the intercept is acceptable or not (one bit). The track and intercept finding are done in parallel in each cell and the two results together used to produce a "good fiducial track". The number of good fiducial tracks is summed across the entire event and a cut placed on this quantity to produce the final fiducial region trigger (Fig. A-4).

We summarize here the time required to form the fiducial region trigger and the scale of the fiducial processor. We have assumed 50 - 100 ns per hit to find hits in the tracking planes and up to 4 hits per half plane. The half planes will be read out in parallel so that this will involve 200 - 400 ns.

The processing cells involve a double add plus a compare in one path (35ns total) and an add plus an MLU in the other path (40 ns) plus a counter increment (allow 10 ns) plus allowing another 10 ns for set up etc. gives a total of  $40+10+10=60$  ns per cycle. There are a maximum of  $4 \times 4 = 16$  cycles for a total time of  $16 \times 60 = 960$  ns.

The total time for the fiducial region trigger is then:

$$960 \text{ ns} + (200-400 \text{ ns}) = 1160 - 1360 \text{ ns}$$

The scale of this processor is quite modest. Each processing cell requires about 14 - 15 chips. There are 4 cells per processor and two processors so one has a total of about 120 chips for all the cells required. The entire processor plus control logic should fit on one board.

The tracking planes should involve less than 600 channels of readout.

## VII. Schedule and Running Time

The raw rate of fiducial volume low  $E_t$  triggers in a 2 MHz beam is very high on the scale of the streamer chamber dead time. Therefore, the rate at which pictures are taken is determined by our choice of recovery or refire time. We have operated reliably at 5 Hz and could in principle operate as high as 10 Hz.

If we choose 5 Hz as a demonstrated rate we estimate the number of spill seconds needed to acquire the 3 million pictures as  $.6 \times 10^5$  or 167 spill hours.

We propose then to run the streamer chamber for a fraction of the of the 791 run. The relatively short time required for the chamber run would also be helpful in minimizing any interference with the purely electronic part of 791. Repairs (if needed) could wait for natural downtimes.

## VIII. Costs

We summarize the costs to complete and install the streamer chamber below.



	Cost (\$1000) Existing Funds	FY1,2	FY3
1. High Voltage Pulsing System			
New Marx Generator	(70)		
Power Supply for Marx Generator		20	
Coupling Tank for New Marx Generator		10	
2. Reliability improvements and spares inventory		30	
3. New large format image intensifier tubes		140	100
4. Modifications to SLAC HRO camera for use with streamer chamber.		20	
5. Move chamber and install in TPL. R.F. shielded enclosure		50	
Rework of plumbing, optics, etc.		15	
6. Fiducial Region Trigger. Processor		20	
Tracking detectors and readout		55	
TOTAL	(70)	360	100

\* FY1 is the current fiscal year.

#### References

- 1 M. Adamovich, et.al. CERN/EP 86-76, 1986 (WA 58)
- 2 E-691 collaboration, to be published.
- 3 P. Cooper, Yale internal note.
- 4 Dave Kaplan, Talk at E-769 group meeting, 18 February 1988

Figure A-2

Drawing of the Streamer Chamber

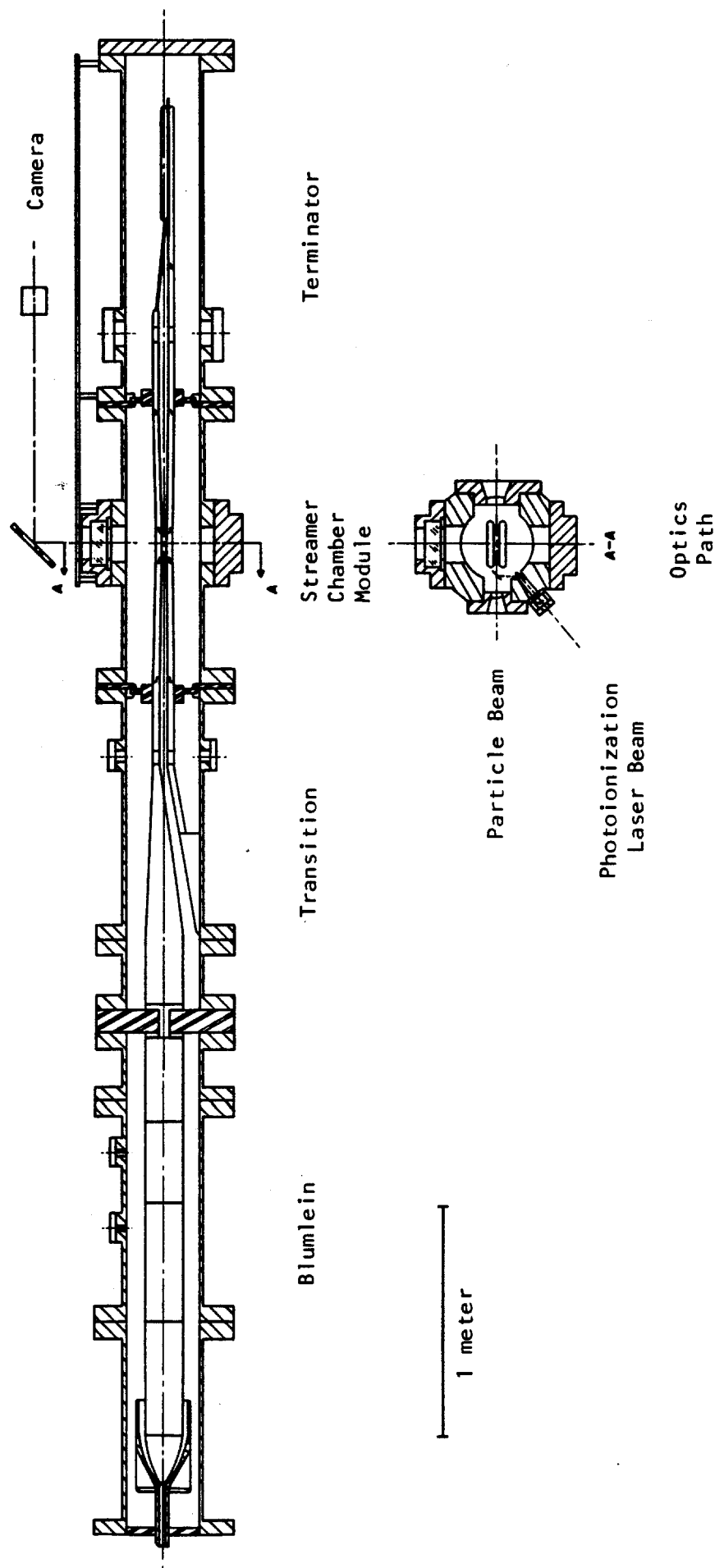


Figure A-1  
Block Diagram of the Streamer Chamber

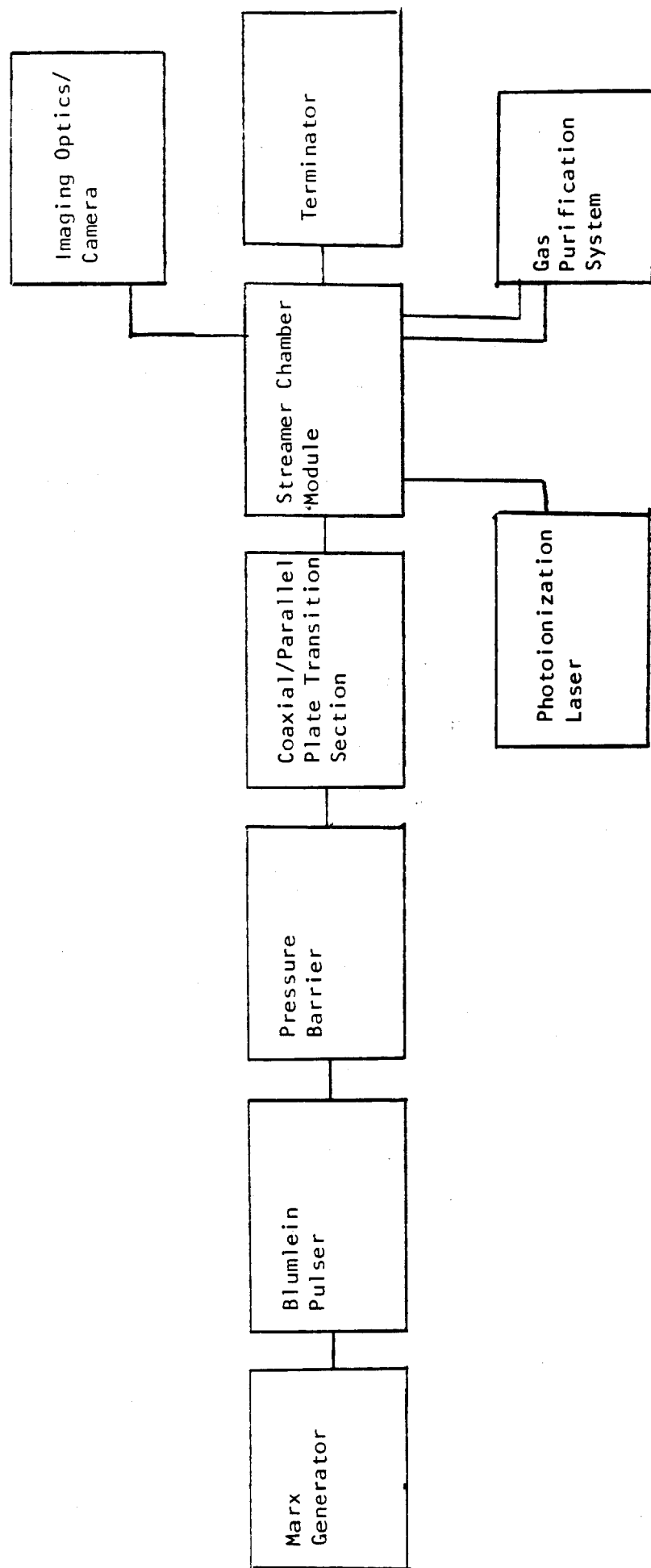
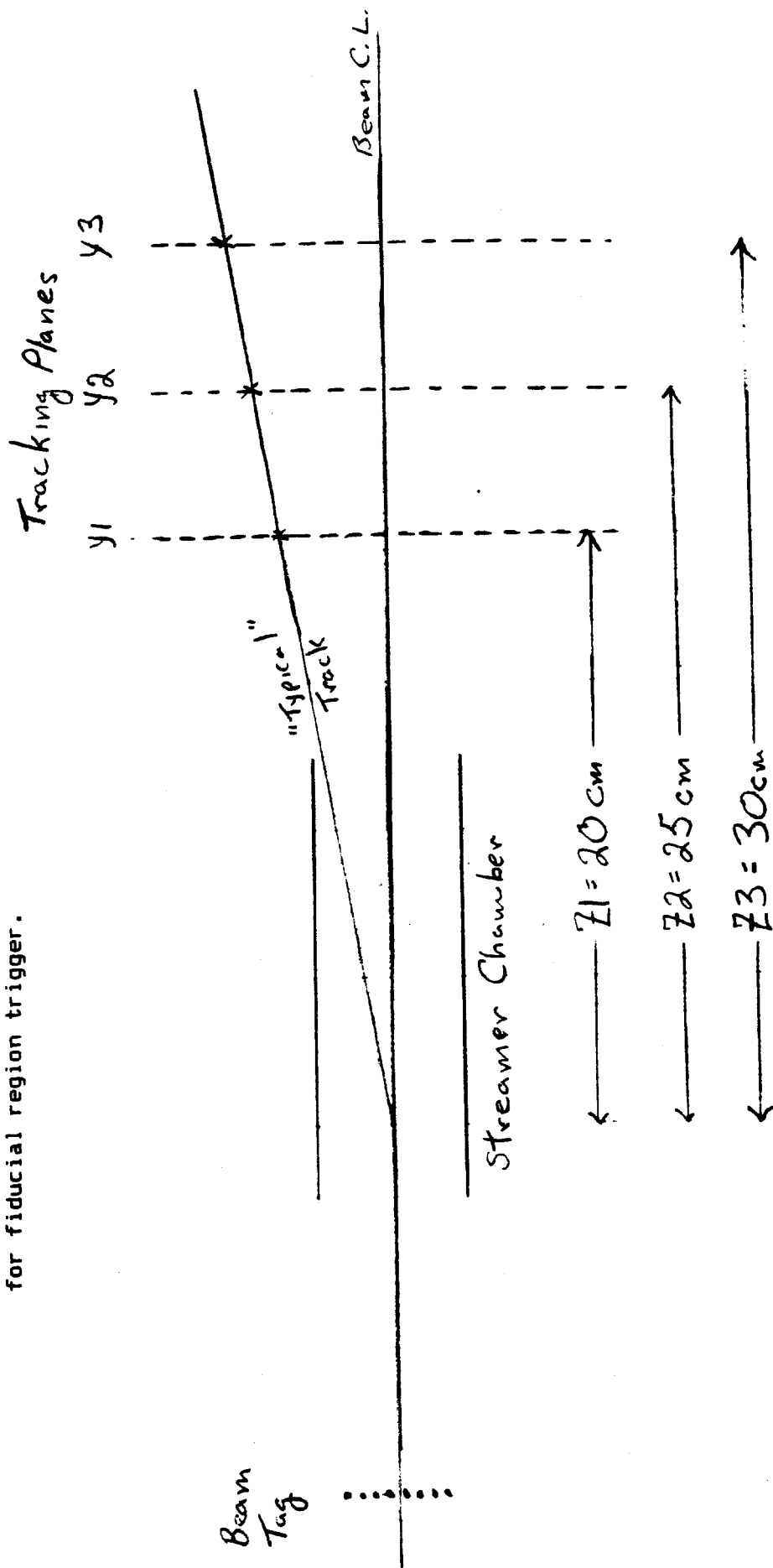


Figure A-3

Layout of Tracking detectors  
for fiducial region trigger.



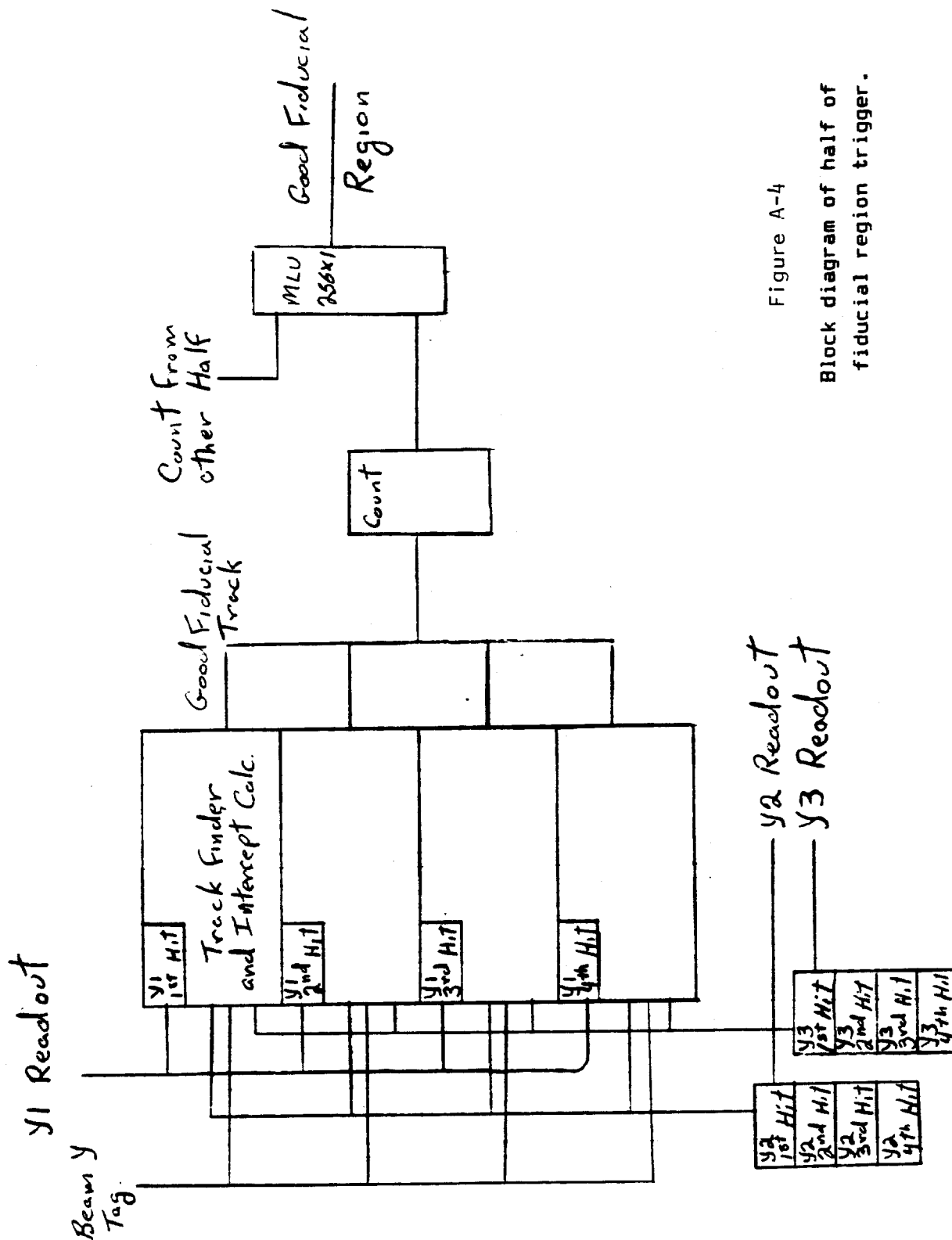
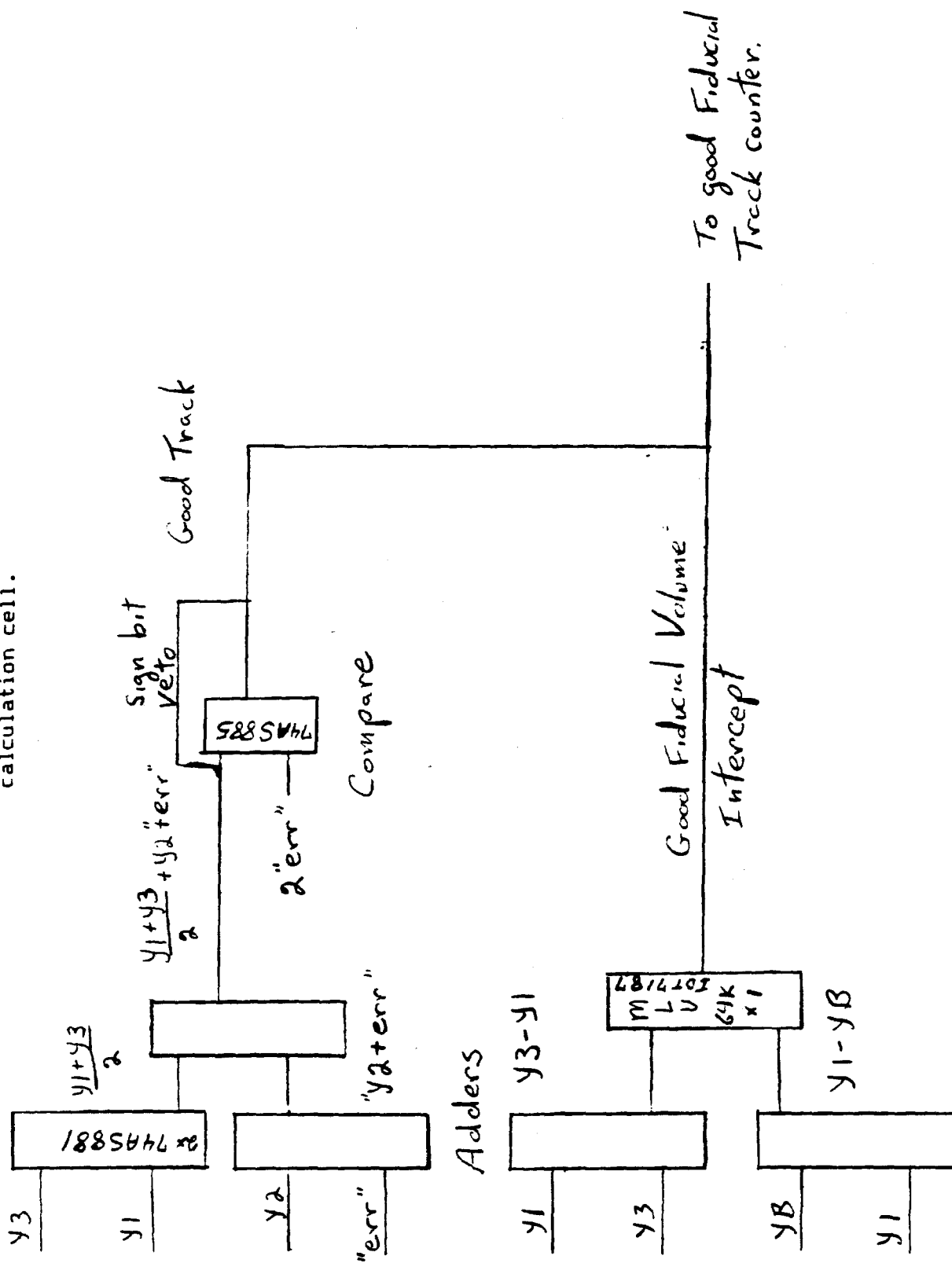


Figure A-4

Block diagram of half of fiducial region trigger.

Figure A-5

Fiducial region trigger calculation cell.



**P791**

**CONTINUED STUDY OF  
HEAVY FLAVORS AT  
TPL**

A Proposal to Fermilab  
March 7, 1988  
by

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AAB 4929

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## I. Proposal Summary:

This is a proposal to continue the series of heavy quark experiments in the Tagged Photon Laboratory (TPL). We propose a two-phase experiment aimed at the eventual study of beauty particles and their hadroproduction. However, we anticipate that very large numbers of interesting charm particle events will be observed along the way.

In the first phase of the experiment, to be run in the next fixed target period, we anticipate accumulating approximately 100,000 fully reconstructed charm particles and a few 10's of fully reconstructed beauty particles. Additional information on beauty production will come from larger samples of less than fully reconstructed beauty decays. For charm, Phase I represents an order of magnitude improvement in signal over E769. In the second phase of the experiment, to be run in the fixed target running period following the upcoming running period, we anticipate accumulating yet another order of magnitude more charm and beauty decay.

The philosophy of this effort is a continuation of the open trigger strategy of E691 and E769. This implies accumulation of very large amounts of data for efficient off-line filtering and analysis using ACP type microprocessor farms. This philosophy is distinct from and complementary to experiments with specific final state triggers.

The very large sample of open charm states will be used to study rare charm meson decays, charm baryons, production correlations and to measure improved values for lifetimes and mixing limits. We are confident of being able to attack these problems based on our first looks at E769 data. We see a signal to background ratio comparable to that achieved in the photoproduction data of E691. This earlier TPL experiment has already demonstrated that the apparatus is capable of producing physics results of a quality formerly imagined only in colliding  $e^+e^-$  experiments. We expect with the new experiment to be able to overcome the statistical limitations of previous efforts.

During a short portion of the run we will operate a high resolution streamer chamber in conjunction with the basic electronic experiment. This will be a sufficient period of time to demonstrate the utility of open triggers for streamer chamber experiments, prove the chamber's physics analysis capability and maintain the option of streamer chamber use for beauty (should the combination of cross-section and advanced trigger capability make this attractive). At the same time, the streamer chamber exposure will provide a unique and complementary look at some interesting charm physics questions. These include cross-sections which can be used to convert ratios of branching ratios to absolute branching ratios, charm production correlations and negative Feynman  $x$  capability. These are described in more detail in the Appendix to this proposal.

The eventual goal of the experiment is to collect a sufficient sample of beauty decays to:

1. separately measure the lifetimes of charged and neutral beauty mesons
2. measure the total and differential beauty cross-section
3. contribute to branching ratio measurements of beauty

While these eventual physics aims will be addressed in Phase I, we conservatively expect that we will obtain only crude numbers. Learning the most effective way to proceed will only come through experience. For this reason we are explicitly planning the two-phase approach outlined above. The apparatus modifications proposed for the next run are all aimed at being useful without change for both phases of the experiment.

The experiment will use the same techniques which were successfully demonstrated for photoproduction in E691 and hadroproduction in E769. We use accurate vertex measurements to select the events of interest and to concentrate reconstruction histograms on downstream vertexing tracks. This both enriches the charm and beauty samples on tape and minimizes the combinatorial backgrounds which plagued heavy flavor hadroproduction experiments of the past.

The basic Tagged Photon Spectrometer detectors (Figure 1) are adequate for the next experiment. The major problem for the experiment is collecting a sufficient number of analyzable events to reach the goals. All of the proposed upgrades for the experiment are directed at this problem. These include:

1. increased beam energy to the Tagged Photon Laboratory
2. reduced event readout dead-time
3. improved acceptance, redundancy and resolution for the silicon microstrip detector system
4. examination of many more interactions using either/both higher data recording rates or/and on-line filtering of events before writing to tape

Phase I of this experiment emphasizes charm physics and a first look at beauty hadroproduction. The system would be run at the highest energies possible in the beamline to the Tagged Photon Laboratory without additional construction, 500 GeV. In Phase II the beamline should be upgraded to transport 800 GeV pions or 1 TeV protons to the laboratory.

The primary trigger for the experiment will be a global transverse energy from the forward calorimeters. This has proved to be successful in previous TPL experiments on heavy flavor. This trigger will be basic to both the electronic and streamer chamber parts of the experiment. The streamer chamber event trigger will however, also include a fiducial volume trigger as described in the Appendix.

## II. Physics Objectives

This experiment aims to go clearly beyond E-691, Mark III, ARGUS, CLEO and other charm experiments in the amount of charm events to be reconstructed. With a data set at least a factor of ten larger than E-691 and with a better silicon vertexing system, we expect to enter a new realm of charm physics. The emphasis on high statistics, better resolution and lower backgrounds than E-691 will enable us to measure many new modes of charm meson and charm baryon decays, to measure charm particle lifetimes precisely, to improve  $D^0$ - $\bar{D}^0$  mixing limits substantially, to better understand charm production and to make progress towards beauty physics in a hadron environment.

In the following sub-sections we elaborate on these assertions, while also referring the reader to the section on comparisons between charm experiments below. As the section on rates explains, we expect about 100,000 fully reconstructed charm events, as opposed to E-691's 10,000. We implicitly use this factor of 10 in the following discussion. For instance, those of E-691's signals which are at the  $2\sigma$  level will become completely unambiguous (some of the  $\Lambda_c$ ,  $D^{**}$ , semileptonic signals — especially unpublished results).

### A. CHARM DECAYS

E-691 and other experiments have begun to measure branching ratios which shed light on the various mechanisms at play in charm decay. The pattern of  $D^0$ ,  $D^+$ ,  $D_s^+$  and  $\Lambda_c^+$  lifetimes<sup>1</sup> point to dominant spectator diagrams without much colour-suppression and small contributions from the exchange and annihilation diagrams for D mesons. However, none of these assertions are completely proven and there remains much else to do for a high-statistics experiment like P-791.

The role of final state interactions is one such example. It appears from decays like the  $K\pi$ ,  $K^*\pi$  and the  $K\rho$  that final state interactions are important.<sup>2</sup> Less well measured is the  $K^0$ - $\bar{K}^0$  decay mode of the  $D^0$ .<sup>3</sup> Finally, E-691 sees a small branching ratio for  $D_s^+ \rightarrow \pi^+\pi^-\pi^+$  relative to  $\phi\pi^+$  and even less evidence of the  $D_s^+ \rightarrow \rho\pi^+$ .<sup>4</sup> This is interpreted as meaning that annihilation diagrams do not play a major role, but again final state interactions could be invoked to explain the small branching ratios. However observation<sup>5</sup> of the  $\bar{K}^0\phi$  decay of the  $D^0$  indicates the importance of non-spectator decays.

P-791 proposes to measure these and other modes which become feasible with a tenfold increase in statistics. The high statistics also allows Dalitz plot analyses of modes such as  $KK\pi\pi$ ,  $KK\pi\pi\pi$ , ... to determine the fraction of decays that come from PP, PV and VV decays (P – pseudoscalar, V – vector). A dominance of two-body modes is motivated by simple considerations and facilitates calculations of many branching ratios.<sup>6</sup> We expect

to measure most modes with expected branching ratios of  $\sim 1\%$  and some modes with expected branching ratios only a little larger than  $0.1\%$ . The  $K^- a_1^+$  and  $K^{*+} K^{*-}$  are examples of the former and the modes  $\rho\rho$  and  $K^{0*}\pi^+$  are examples of the latter branching ratios.

Another interesting area of charm decays is semileptonic modes. Higher resolution and lower backgrounds help these decays as much as the higher statistics because the missing neutrino energy degrades resolution considerably. Because of poor statistics to date even the modes observed so far such as the  $K^- e^+ \nu_e$ ,  $K^- \pi^+ e^+ \nu_e$  and the  $\bar{K}^{*0} e^+ \nu_e$  will gain from higher statistics. In addition, we hope to be able to see  $\rho e^+ \nu_e$ , the KM-suppressed  $\pi^- e^+ \nu_e$  mode (and learn about the KM-matrix element  $V_{cs}$ ) and similarly to observe the  $D_s^+$  decays into  $\phi e^+ \nu_e$  and  $\eta e^+ \nu_e$ . A study of semileptonic decays could point to extra generations through lack of unitarity in the KM matrix. In any case, we expect to measure form factors in the decays and polarization of the  $K^*$ s. Finally, with higher statistics we could extend these studies to the semi-muonic modes and possibly even look for purely leptonic decays such as  $\mu^+ \nu_\mu$  and  $\tau^+ \nu_\tau$  which directly yield the pseudoscalar coupling constants.

Other decay modes of interest include charm-changing neutral currents (for which we can improve the E-691 limits), singly and doubly Cabibbo-suppressed decays and decays from other interesting diagrams (such as destructive Pauli interference, Penguin diagrams, Hairpin diagrams etc. — see ref. 7 for a recent review). We also feel that entering the new regime of small branching ratios will inspire theorists to revisit charm decays and predict even more branching ratios and identify their interesting features.

While there has been much work in the field of charm meson decays, there is still a lack of good statistics for charmed baryons. We expect to confirm and accurately measure the relative branching ratios of the  $\Lambda_c^+$  into  $pK^- \pi^+$ ,  $pK_s^0$ ,  $pK_s^0 \pi^+ \pi^-$ ,  $\Lambda \pi^+$  and  $\Lambda \pi^+ \pi^+ \pi^-$ . Further, we can search for other modes for the  $\Lambda_c^+$  decay and combine the observed  $\Lambda_c^+$  with pions and kaons to look for the  $\Sigma_c$  multiplet. There is controversy over the mass of at least two of the members of this multiplet<sup>8,9</sup>. Finally, we should be able to see the  $\Xi_c^+$  and other charmed baryons if they decay into simple charged modes and extend the search for the  $D^{**}$  mesons.

## B. $D^0$ - $\bar{D}^0$ MIXING

The Standard Model predicts strong suppression of  $D^0$ - $\bar{D}^0$  mixing due to the s-quark dominance in the well-known box diagram in contrast to the  $K^0$ - $\bar{K}^0$  system where the c-quark dominates. As a consequence, it is widely assumed that measurement of a substantial

rate of  $D^0\text{-}\bar{D}^0$  mixing would be a signal of new physics beyond the Standard Model. The Standard Model predicts the correct phenomenology of the  $K^0\text{-}\bar{K}^0$  system, at least at the order of magnitude level, whereas some extended technicolor theories and left-right symmetric theories have failed this test<sup>10</sup>. In the case of  $D^0\text{-}\bar{D}^0$  mixing, it is also possible to produce a flavor-violating ( $\Delta c = 2$ ) transition by a product of weak-interaction processes to specific mesonic intermediate states<sup>11</sup>. These “doubly Cabibbo suppressed decays” (DCSD’s) are expected to occur at a rate one or two orders of magnitude greater<sup>11</sup> than box-diagram predictions.

The current interest in  $D^0\text{-}\bar{D}^0$  mixing stems from the possible observation of a high-level of such mixing from Mark III<sup>12</sup> whose 3 “mixed” events on a background of  $0.4 \pm 0.1 \pm 0.1$  (out of 162 “unmixed” events) can be interpreted as mixing at the 1.5% level. E-691 however, find that  $D^0\text{-}\bar{D}^0$  mixing is below 0.4% at the 90% CL. The E-691 result is further strengthened by the fact that they are sensitive to the time development of mixing, as would be P-791. E-691 is only about a factor of 2-3 away from the sensitivity required for observing DCSD’s. P-791 should therefore not only improve  $D^0\text{-}\bar{D}^0$  mixing limits but also be able to observe DCSD’s. We expect P-791 to be sensitive to mixing at the 0.1% level.

In summary, if mixing is not observed, P-791 should set a limit below the theoretically expected level of DCSD’s. If it is observed, the P-791 analysis will allow separation of box-diagram mixing from DCSD’s. In this case, the branching ratio for wrong-sign decays would be measured for the first time.

### C. PRECISION LIFETIME MEASUREMENTS

E-691 has contributed the best lifetime measurements of charm particles to date. Their measurements of the  $D^+$ ,  $D_s^+$ ,  $D^0$  and  $\Lambda_c^+$  lifetimes are  $1.090 \pm .030 \pm .025$  ps,  $0.47 \pm .04 \pm .02$  ps,  $0.422 \pm .008 \pm .010$  ps and  $0.22 \pm .03 \pm .02$  ps<sup>1,14</sup> respectively. As can be seen, these lifetimes are beginning to be limited by systematic errors. It can be asked whether the factor of 10 increase in statistics anticipated will be thwarted by insurmountable systematic effects. The answer is clearly no, if we examine the sources of E-691’s systematic effects. The major errors come from uncertainties in the absorption and scattering cross-sections of the charm decay products (and even the charm itself!). These uncertainties and z-dependent acceptance corrections both become small with the simple expedient of switching to a foil target. Further, with a high-resolution Silicon system, we should comfortably be able to keep the systematic errors below the statistical errors.

A precision measurement of lifetimes will set the standard for several years and could inspire theorists to calculate all the decay diagrams. In particular, if the non-spectator

diagrams which affect the equality of the ratio of  $D^+$  and  $D^0$  lifetimes and the ratio of their semileptonic branching ratios are calculated, an important relation in charm decays can be precisely tested.

#### D. PRODUCTION OF CHARM

While charm production studies are not expected to be the major impetus of this experiment, the sample of hadroproduced open charm states written to tape will be at least an order of magnitude larger than any previous or concurrent sample, including that from E-769. This statistical power can be exploited in making detailed comparisons with the various theoretical models in regions of the kinematic variables where there have previously been only a small number of events. Also, windows to as yet unexplored kinematic regions will be opened up by the increased acceptance.

The QCD fusion model is unable to accommodate a leading component to charm hadroproduction or an  $A$  dependence of the form  $A^\alpha$  where  $\alpha$  is not 1. E-769 should certainly be able to put these measurements on solid ground. However the statistics at large  $x_F$  may not be large. P-791 will enable a sensitive measurement in this kinematic region. The increased acceptance will extend the  $p_T$  region that can be explored. QCD is expected to give better predictions at high  $p_T$  as already established for QCD jets above  $\sim 5$  GeV.

Statistics should be sufficient to allow a measurement of production polarization for one of the more copious states of non-zero spin. Hyperons containing strange quarks show large polarizations<sup>15</sup> in production. As yet there are no theoretical models which explain this phenomenon.

The number of events for which both charm particles will be accepted is expected to be as much as 20 times larger than the sample obtained in E-691. E-691 expects to publish results based on 100 charm pairs and E-769 should similarly expect to see about 70 charm pairs. This is based on the measured LEBC charm cross-section<sup>16</sup> and assumes identical acceptance for E-691 and E-769. If we make the same assumption of acceptance we obtain 700 charm-pair events for P-791, while another factor of 2 in acceptance increase will lead to 1400 such events. We expect another factor of 2 due to the improved geometric acceptance alone (see tracking upgrade section below) and another improvement due to the higher beam energy.

Of compelling interest in these data will be studies of associated production for which only a handful of events have been seen to date<sup>17</sup> and measurement of the average  $p_T$  of the charm pair which appears to be much larger than expected in the only measurement

yet attempted.

## E. BEAUTY PHYSICS

This experiment emphasizes an open geometry, high statistics, large acceptance and fine resolution for lifetimes. These features are ideally suited for charm physics, but are also essentially what is needed for a first beauty experiment. We expect to measure B lifetimes, the  $B^0$ - $B^+$  lifetime difference, the total and differential beauty cross-sections, fully reconstruct some decays and perhaps even study the time evolution of mixing. Because the B-mesons are boosted to  $\gamma$  values of  $\sim 30$ , their reconstruction is made easier than at collider energies.

For a run lasting  $2 \times 10^6$  seconds, a 5% target, a 2MHz beam and a  $\sigma_{b\bar{b}}/\sigma_{TOT} = 3 \times 10^{-7}$  at 500 GeV, one obtains a total production of 60,000  $B\bar{B}$  pairs. The total trigger efficiency and livetime effects reduce this number to  $\sim 50,000$   $B\bar{B}$  pairs.

For total cross-section studies, it is enough to exploit the semileptonic branching ratio or the branching ratio into  $D^{*+}$  mesons. For most other studies, it is necessary to fully reconstruct decays. Assuming .001 reconstructed B mesons per produced B event, we are left with only 50 fully reconstructed decays. This underscores the importance of background reduction (implying a high-resolution and high-redundancy silicon system). It is extremely hard to model the backgrounds which could be large. The experiment should provide a direct measure of these backgrounds and our data should be a fertile testing ground for B-trigger ideas because of our open geometry.

However, the topological branching ratio into leptons and  $D^{*+}$  mesons can be utilized to obtain a total cross-section, lifetimes and even some differential cross-section information. The useful topological branching ratio into  $D^{*+}$  is about 1.7% and the fully reconstructable semileptonic modes are 0.9% and 1.4% for the neutral and charged B mesons respectively. The inclusive cross-section into leptons is known to be about 22%, with about half that number at high  $p_T$  ( $> \sim 1$  GeV). Thus, we should see about 7000 events with high- $p_T$  leptons from B mesons and about 700 events with two high- $p_T$  leptons. Finally, there are expected to be 1.15 charm particles per B meson decay. We could thus also obtain the B cross-section from the number of D mesons which do not point back to the primary vertex.

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### III. Required Upgrades

#### A. Introduction

The three major upgrades requested in this proposal are an order of magnitude increase in the data acquisition, an increase in coverage and redundancy of the silicon microstrip detector system (SMD), and an increase in the beamline energy. These will help us obtain more heavy flavor events, particularly those where both heavy flavor particles can be detected. In addition, the greater redundancy and higher resolution of the SMD system will effectively increase the number of charm events detected and will reduce backgrounds. Doing high statistics charm and catching any beauty events requires either an increase in the E769 data acquisition rate, or trigger enrichment, or both. We propose to continue the successful direction of experiments at TPL, which is to depend as little as possible on substantial trigger enrichment, and to apply our efforts instead to improving the data acquisition system already developed for E769.

#### B. Data Acquisition System

The philosophy of TPL experiments has been to avoid any dependence on trigger processors, due to cost, manpower, and workability. If an impact parameter trigger processor were used for P791 (e.g. based on finding tracks in silicon microstrips), it would have to operate exceedingly fast. A third level trigger (consisting of an ACP processor farm, for example) might work; but would still require an upgrade to a faster front-end readout, and would have the potential to slow down the data taking and to cause possible trigger biases. Use of an offline farm of ACP processors avoids these problems. We currently estimate that 120 of the Motorola 68020 ACP processors will be able to analyze the 450 million events taken by E769 in six months. The projection is based on the assumption that a fast software filter, which demands the possibility of multiple vertices, will reduce the total reconstruction time by a factor of 4. P791 will use a similar offline filter in upgraded ACP processors. (The ACP group is currently developing a processor, based on the MIPS chip [1], which has been benchmarked to be 10 times faster than what is now used). The obvious problem of storing large amounts of data at reasonable cost is addressed below in section 6.

In order to achieve the physics goals of Phase I of the proposal, we need to increase the data taking rate by a factor of 12. Phase II can attain an additional factor of 4. The E769 DA system [2-5] currently logs 400 events (each 4 kilobytes long) per spill-second. The current E769 front end readout speeds are roughly 300 to 900 microseconds. To write 20,000 events per spill-second with 30% dead time in Phase II, P791 requires front end readout speeds of 15 microseconds. Sten Hansen of the Fermilab Physics Dept. is developing, for D0, TDC's and ADC's which are read out in 10 to 20 microseconds. We propose to use these devices, and upgrade the DA system to operate at the higher data taking rates.

The overall architecture of the new system is shown in Fig. 2. The digitizing electronics are triggered to read out, and the data passed in several parallel data streams. A busy signal raised during digitization prevents further triggers. The event fragments are stored in FIFO memory buffers on each data path. The buffers have the capacity to store a whole spill of data. The data in each FIFO moves on, during the spill and interspill, to dual port buffers in a VME crate, where event building takes place. By placing the large amount of memory upstream, the event building can occur continuously, and not just during the spill. The assembled events are then sent to an I/O port and onto tape. Selected events are also sent to a VAX for monitoring. The boss CPU supervises the system. At each stage in the system, Busy/Ready signals are sent from downstream devices to upstream devices, e.g. if the tape is still busy, the dual port buffers are forbidden to receive any more data; if any of the FIFO's fills up, it signals the associated digitizer, which then holds off experiment triggers. This is exactly the scheme employed successfully in E769.

The following sections describe each of the parts in more detail. Note that we are currently planning to extend the data acquisition architecture which has proven to be very successful and trouble free during the E769 run. We present one implementation of this scheme, but others are also being considered. We use the presented scheme as a proof of principle and to estimate costs.

## 1. New TDC Electronics

E769 uses one LeCroy 4298 TDC channel for each of 6304 drift chamber wires. In a typical event, only 5% to 10% of these wires are actually hit and need to be digitized. The TDC's being developed by the Fermilab Physics Dept. perform the data sparsification before digitizing, making the readout time of the devices faster than the LeCroy units.

The new electronics handles 64 channels per card. Two time to voltage converters are provided per channel to record double hits. One flash ADC is then used to digitize only the channels that are hit. Fast analog CMOS switches are employed to multiplex each channel without biasing the charge that is being read out. The digitization time is 1 microsecond per hit. The time to get the address of the channel and be read out is less than 50 nsec. The flash ADC which looks most promising is the 11-bit Micro Power Systems [6] MPS7685 (\$36 each in 100's). The TDC modules fit into a Eurocard crate which also contains a crate controller similar to the Smart Crate Controllers used in E769. The output from the controller goes onto an RS-485 bus at a rate of up to 40 MB/sec.

## 2. New ADC Electronics

E769 uses LeCroy 2280 and 2249 ADC's to digitize 536 calorimeter and Cerenkov channels, of which about 40% are hit in a typical event. Like the LeCroy TDC's, digitization occurs first. The new ADC electronics being developed by the Fermilab Physics Dept., which perform sparsification before digitizing, will be faster than the LeCroy system.

Each channel in the new system stores the charge received during an event gate. A discriminator is used to determine if a user set level is passed; if so, the channel is digitized. As in the TDC's, fast analog CMOS switches are used for multiplexing. Twelve bits of dynamic range are required. To achieve this one could either use two 11-bit ADC's in series such as the MPS7685 used by the TDC's, or one could use a single 12-bit flash ADC such as the Crystal Semiconductor [7] CS5212 (\$185 each). Each module will have 64 channels multiplexed to two ADC's, i.e. 32 channels per 12-bit ADC. The modules fit into the same type of crate as the TDC cards, and use the same type of controller.

## 3. New Silicon Microstrip Readout

E769 has about 9000 silicon microstrip channels. When a channel is hit, a bit is set in a shift register on an amplifier-discriminator card. Eight scanners are used to shift the bits out in parallel and to sparsify the data. A typical event has 200 hit channels, and shifting a bit requires 100 to 200 nanoseconds. If the scanners are modified to shift 150 bits at 100 nanoseconds per bit, the SMD's can be read out in 15 microseconds without changing the current amplifier-discriminator cards; only the scanners need to be upgraded. A CAMAC based scanner is being developed by Fermilab for E665. Sixty such scanners would be required. Four scanners fit in a module, so 15 modules would be housed in three CAMAC crates. About 200 16-bit words then need to be read out of the CAMAC crates. The current E769 Smart Crate Controllers can be adjusted to read out at faster than normal CAMAC speeds, up to 200 nsec per 16-bit word, if the modules in the crates are capable of this.

Another possibility is the silicon microstrip readout system being developed by the Fermilab Research Division for E771. This system puts the required amplification, delay, discrimination, buffer and zero suppression functions onto a custom chip.

## 4. FIFO Memory Buffers

The data from each crate of TDC's, ADC's and SMD scanners are stored in a FIFO memory buffer. If the tape writing speed is kept at 8 MB/sec during the 34 second interspill, then a total of  $34 \times 8 = 272$  MB total of memory is needed. If there are 10 crates of data being read in parallel, then each data line needs about 28 MB of memory. Buffering the data before rather than

after event building allows the event building to proceed not just during the spill but during the interspill as well.

Al Baumbaugh and others [8,9] have developed a simple FIFO memory system for E687. Four MB of memory fit on each electronics card in the form of 256K dynamic RAMs. We would need an average of seven memory cards plus a FIFO controller card for each of the 10 crates on the parallel data paths. The inputs and outputs of the system are simple and run at a speed of at least 60 MB/sec. Each uses a bus with 32 data lines, one ground, one strobe; the levels are TTL.

## 5. VMEbus Event Builder

In E769, event fragments move from seven Smart Crate Controllers to seven dual port double buffers. ACP CPU boards assemble the event fragments by collecting them out of the buffers and then send the assembled events to a tape controller. The buffers only allow one word at a time to be moved. Block transfers, which would be faster, are not supported. There are at least two ways to speed the process up :

- a) Replace the buffers with ones that allow block transfers. The Ironics [10] IV-3272 VMEbus Full Speed Data Transporter looks like a good candidate for this function. It has an RS-485 interface.
- b) Do not move the data over the VMEbus twice as it is done in E769. This means that the tape controller should reside on the same board where events are assembled. There are several CPU boards available with Small Computer System Interface (SCSI) ports (e.g. the Omnibyte OB68K/VSBCI [11] ). We need to find one with adequate performance. Alternatively, we might use an SCSI controller board with enough memory to buffer a few events.

## 6. Tape Drive System

How does one write to tape at 8 MB/sec? The following table presents 5 options. The first option is just to use more 0.6 MB/sec 9-track drives like we used in E769. The total cost of the tape needed for P791 rules out this option, as well as the IBM 3480 cartridge drives. The Haystack Observatory [10] tape drive is to be used by the Very Large Baseline Array; it looks promising, but only one prototype exists today. Both the Honeywell [11] Very Large Data Store (VLDS) and the Exabyte [12] EXB-8200 are commercially available, although Honeywell has only shipped two dozen drives so far. The tape cost per 1000 hours of running is reasonable in both cases, and actually quite cheap for the Honeywell.

The number of Exabytes required is somewhat unwieldy due to its low 0.25 MB/sec speed. It does have a 1/4 MB buffer that accepts data at 1.5 MB/sec. At some point Exabyte may introduce a new version with double the speed and twice the density. Honeywell expects to upgrade their drive from 2MB/sec to 4 MB/sec in the near future. The high cost of the Honeywell reduces the number of drives that can be purchased; it is only cost effective in high speed applications. We intend to choose either the Exabyte or the Honeywell drives. The current delivery time quoted for the Honeywell is seven months, while the Exabyte is packaged and sold now by numerous vendors [15].

Both the Honeywell and Exabyte are available with a SCSI interface. A SCSI to VME controller called the Rimfire 3510 is made by Ciprico [16]. It will pass data on the SCSI bus at between 2 and 5 MB/sec. Either one Honeywell or about 4 Exabytes would be connected to such a controller. A number of other companies also make SCSI controllers for this and other buses.

# TAPE DRIVE COMPARISON

DRIVE	9-TRACK	IBM 3480	EXABYTE	HONEYWELL	HAYSTACK
tape width	1/2"	1/2"	8mm	1/2"	1"
tracks	9	18	819 TPI	400TPI	512
# of heads	9	18	1	2	~32
tape length	2400'	540'	360'	807'	28000'
bits/inch/track	6250	18936	~40,000	~40,000	~35,000
speed (MB/sec)	0.6	3	0.25	4	24
# of drives	13	3	32	2	1
spare drives	3	1	4	1	1
\$/drive	\$10,000	\$50,000	\$3210	\$39,900	\$80,000
drive cost (includes spares)	\$160,000	\$200,000	\$115,560	\$119,700	\$160,000
GB/tape	0.16	0.22	2.3	5.2	750
time/tape	4.5 min	1.2 min	2.5 hrs	22 min	22 hrs
tape changes/hr	175	150	13	6	1/22
\$/tape	\$10	\$12	\$6	\$4	\$800
tapes/1000 hrs	175,000	150,000	13,000	6000	45
tape cost	\$1,750,000	\$1,800,000	\$78,000	\$24,000	\$36,000
TOTAL	\$1,910,000	\$2,000,000	\$193,560	\$143,700	\$196,000

## 7. Summary and Cost

We propose to upgrade the E769 DA system from 400 events per spill-sec to 5000 events per spill-sec in Phase I, and by an additional factor of 4 for Phase II. We intend to upgrade our front end electronics by multiplexing many channels into a single flash ADC. 280 MB of FIFO memory is required in Phase I to buffer a spill. New dual port buffers, which allow fast block transfers, are required for the VMEbus. Tape controllers and event building will be integrated so that events will only be moved once across the VME backplane. Finally, enough video tape drives must be run in parallel to write data at the rate of 8 MB/sec continuously. Offline filtering and reconstruction will be performed on the next generation of ACP processors.

Total DA upgrade cost estimate (spares included)

7000	TDC channels @ \$20 each	\$140,000
700	ADC channels @ \$40 each	\$ 28,000
10	Eurocard Crates @ \$2000 each	\$ 20,000
10	Crate Controllers @ \$2000 each	\$ 20,000
15	SMD Scanner Boards @ \$2500 each	\$ 37,000
12	28 MB FIFO memory buffers @ \$2500 each	\$ 84,000
12	RS-485/VME buffers @ \$3700 each	\$ 44,400
8	CPU/SCSI Controller Cards @ \$4000 each	\$ 32,000
	Tape Drives (not including tapes)	\$115,000
TOTAL		\$520,900

### C. Silicon Microstrip Detector System

We propose to upgrade the acceptance of TPL's spectrometer while improving its redundancy and resolution at the same time. This improvement is important to the experiment in as much as it helps us obtain more charm events, certainly a vastly improved number of events with both charmed particles reconstructed; and it is the only effective way to fully reconstruct beauty events. The better resolution would substantially improve our reconstruction of semi-leptonic events, reduce backgrounds, and allow us to use lower momentum tracks. The importance of these low momentum tracks cannot be understated for finding rare high-multiplicity states which are a major thrust of this experiment.

The present acceptance of TPL is limited by the downstream apertures of our two magnets, M1 and M2, to approximately 100 mrad. We propose increasing this acceptance to between 200 and 250 mrad, improving the redundancy of track finding near the vertex and reducing the track errors at the vertex. We could achieve this by adding ten 100 micron planes to the present system, reconfiguring the present planes and moving the entire system closer to the magnet. The present E769 SMD system (refer to Fig. 1) consists of : two 25 micron strip planes upstream of the target for beam location, two 25 micron strip planes downstream of the target, followed by nine 50 micron strip planes.

To achieve the 200 to 250 mrad acceptance goal, 10 silicon planes (5 cm x 5 cm) are configured as doublets (including the 9 existing 50 micron planes) within 10 cm of the target. Each doublet has strips at 90 degrees to each other, with the orientation of the doublets optimized for track finding efficiency. The doublets are 2 cm apart, starting after the 25 micron downstream planes used in E769. In addition, 5 more doublets of 100 micron strip planes, of a larger transverse dimension (10 cm x 10 cm), will be placed downstream of the 5 cm x 5 cm doublets. The target itself would be 150 cm downstream of its present position, and therefore closer to the drift chamber stations and the magnets.

The only possible disadvantage of moving the target closer to the spectrometer is a degradation of 2-track separation. However, we circumvent this problem by using new 2-hit TDC's on the drift chambers (see DA upgrade section). The limiting factor is then shaping times for pulses from the drift chamber pre-amp cards, which can be clipped, leading to (conservatively) a minimum drift time separation of about 70 ns (0.28 cm).

We are aware that the acceptance upgrade can be further optimized in various ways, such as spacing SMD planes out further, but making them larger in transverse size (this would alleviate space shortage for cables, etc.).

We have studied the effect of the upgrade on the geometric acceptance of single charm, 2-charm, and beauty events as a function of maximum angle ( $\theta$ -max) and of lowest momentum decay track ( $p$ -min) for the most copious decay modes (see Figs. 3, 4 and 5). Changing  $\theta$ -max and  $p$ -min from 133 mrad and 4.0 GeV (E769 values) to 225 mrad and 2.5 GeV (P791 values) leads to typical acceptance increases of 22% for single charm events, 90% for 2-charm events and 50% for beauty events. The upgrade also improves tracking in general. Anyone familiar with the E691 analysis will concede that the "Category-3" tracks contain a lot of background; and they are also numerous enough to cause combinatoric backgrounds in mass plots by themselves. Category-3 tracks are tracks that only went through the silicon (and D1) and D2, but not through D3. Our upgrade ensures that some of the tracks that would have only gone through D2 now go through D3 as well. Further, tracks close to corners of D2 (not fully reconstructed) now go through the main body of that drift chamber. This effectively allows us to use lower momentum tracks in our analysis. In addition, more tracks will go through the Cherenkov counters.

The momentum and angular resolutions of the detector remain essentially unchanged, while the resolution of the projected track position at the vertex improves. This coupled with the larger geometric acceptance ( and background reduction from greater redundancy ) means the silicon upgrade should effectively increase signals by a factor of 2 even for single charm, and of course larger factors for 2-charm and beauty events. The upgrade is expected to cost about \$300K.

#### D. Beamline Upgrade

One expects that the cross sections for heavy flavor production will increase rapidly with beam energy. In particular, by increasing the maximum TPL beam energy from 300 to 500 GeV, we expect a factor of three increase in the beauty cross section and an 80% increase in charm. The added energy also causes a Lorentz boost, which increases the acceptance of the spectrometer for heavy flavor decays. As previously outlined, we intend to add double hit TDC electronics and more planes of silicon microstrips to exploit these Lorentz boosted events.

P791 requires a 2 MHz 500 GeV negative hadron beam. The graph in Fig. 6 plots the E769 secondary beam rate vs a random sampling of run numbers, showing that the apparatus has already functioned at a greater than 2 MHz rate. The proposed beamline combines the preliminary targeting scheme of E769 to produce a zero-degree hadron beam and the secondary beam transport of E691 which maximized the luminosity, upgraded to 500 GeV. Following a preliminary design study for the beamline by Larry Spires, beamline physicist, we believe that the upgrade to 500 GeV requires the addition of two 4-2-240 dipole magnets and a few 3Q120 quadrupole magnets. The new layout will fit within the existing enclosures. In addition, an upgrade for the PS4 sub-station is required. These upgrades are addressed in the existing implementation plan prepared by the Research Division. The cost is estimated to be about \$300K.

Scaling the flux obtained for E769 by the E691 secondary beam transmission, and using curves calculated for the MW beam to scale to 500 GeV, leads to a primary intensity requirement of  $1 \times 10^{12}$  800 GeV protons per 23 second spill.

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- [16] Ciprico, 2955 Xenium Lane, Plymouth, MN 55441

#### IV. Rates, Running Time and Schedule

##### Rates

We estimate the charm and beauty yields from the following assumptions:

Beam	500 GeV/c $\pi^-$
Spill Seconds per Run	$2 \times 10^6$
Target	5% interaction length
Charm pairs/interaction	$10^{-3}$
Beauty pairs/interaction	$3 \times 10^{-7}$ (6 nb)
D.A. System Rate Capability	5,000 events/spill second @ 10% deadtime
Low Et Trigger Rejection	$1/6 = .167$
High Et Trigger Rejection	$1/30 = .033$
Charm Particle Trigger, Acceptance, and Reconstruction Efficiency per Produced Charm Event	$.5 \times 10^{-2}$ (based on E691)
Beauty Particle Trigger, Acceptance, Reconstruction Efficiency per Beauty Event	.1%

Experience in E769 indicates that the high Et trigger rate will be 1/5 of the low Et trigger. Taking a 1/10 prescale factor gives the number of low Et trigger recorded events/spill second as:

$$2 \times 10^6 \text{ beams} \times .05 \text{ int rate} \times .9 \text{ live time} \times .167 \times .1 \text{ prescale} = 1500$$

The number of high Et trigger recorded events/spill second is:

$$2 \times 10^6 \text{ beams} \times .05 \text{ int rate} \times .9 \text{ live time} \times .033 = 2970$$

The total, 4470, is consistent with the data acquisition recording rate.

The number of "useful" charm particles per second, i.e. those that will end up as part of a physics result is:

$$2 \times 10^6 \text{ beams} \times .05 \text{ int/beam} \times 10^{-3} \text{ pairs/int} \times .9 \times .1 \times$$

↓  
?



$$.5 \times 10^{-2} \text{ efficiency} = 9 \times 10^{-2} \text{ c particles/spill second}$$

or:  $.9 \times 10^5$  totally reconstructed charm decays

The number of "useful" beauty particles per second is:

$$2 \times 10^6 \text{ beam/sec} \times .05 \text{ int/beam} \times 3 \times 10^{-7} \text{ b pairs/int} \times .9 \times .001 \text{ efficiency} = 2.5 \times 10^{-5} \text{ b particles/spill second}$$

or: 50 totally reconstructed beauty decays

As discussed in the physics section, it may be possible to recognize beauty particles by a D which does not come from the primary vertex and/or high pt electrons which miss the primary vertex, giving an increase in efficiency:

700 partially reconstructed beauty decays

### Schedule and Running Time

Given a prompt approval, we believe that the three major upgrades will be ready in time for a June 1989 run. The  $2 \times 10^6$  spill second run assumed in the section on rates corresponds to 4 calendar months for 100 hour weeks. Adding this to the necessary 2 to 3 month commissioning period and allowing for accelerator and experiment downtime, etc. gives a conservative 7 - 9 month run.

## V. Cost Summary

The new costs for this experiment are summarized here for the three upgrades described earlier.

1.	Beam Upgrade(all new components) (September 18, 1987 estimate by Larry D. Spires)	\$245K - \$350K
2.	Data Acquisition System	\$521K
3.	Upstream Tracking Upgrade (10 planes of SMD's @ \$30K per plane)	\$300K
	Total	\$1066K - \$1171K

## VI. Comparison with Other Experiments

### A. Charm Experiments

To date there have been several groups studying charm production and, in particular, examining  $D^0$ - $D^0$ bar mixing, rare charm decays, and events in which both charms are observed. Table VI.A summarizes these experiments and their status as well as could be determined.

Results from some groups are partial and for others only estimated. Comparing these experiments to the one being proposed it is clear that no other existing experiment provides the statistics required to study the physics in the detail which P791 would allow.

#### $D^0$ - $D^0$ bar Mixing

One experiment has claimed evidence for mixing, others have been able to place upper limits on it. Mark III has reported (1) observation of 3 wrong-sign decays and 162 right-sign decays in a sample of  $D^0$ - $D^0$ bar decays of the  $\psi''$ . This gives an apparent rate of  $3/(2 \times 162) = 0.009$ , or:

$$r = 0.9\% \pm 0.5\%$$

The background was estimated to be  $0.4 \pm 0.2$  events from other sources. All three events involved a  $\pi^0$  in addition to the two charged pseudoscalars. Mark III has more recently extended this analysis to include fully reconstructed events containing either a hadronic plus a semileptonic decay, or two semileptonic decays (2). This was motivated by the fact that DCSD's do not contribute in the case of identical final states (3). They found no wrong-sign mixing candidates in either of the semileptonic samples (69 and 12 events respectively). If the 3 wrong sign events are then assumed to be all DCSD's, Mark III quotes  $\rho^2 = 5 \tan^4(\theta_c)$  with an error of about 60% (2). ( $\rho^2$  is the ratio of DCSD's to right-sign decays in the notation of Bigi and Sanda.)

ARGUS recently published results (4) of a search for  $D^0$ - $D^0$ bar mixing, using cascade decays of the  $D^{*+/-}$  to tag the  $D^0$  or  $D^0$ bar. They found no wrong-sign decays in a sample of 162 events. Their limit is then:

$$r < 1.4\% \text{ at } 90\% \text{ C.L.}$$

E691 performed a more extensive analysis (5) using the same technique on their complete data. Two decay channels were studied:  $D^0 \rightarrow K \pi$  and  $D^0 \rightarrow K \pi \pi \pi$ . This experiment was able to separate the effects of  $D^0$ - $D^0$ bar mixing from DCSD's by studying the effects of lifetime cuts on their data. DCSD's have a decay rate which decreases exponentially, while the box-diagram mixing gives an additional factor of  $t^2$ . They find no evidence for mixing in either mode, and quote a value of  $r = 0.0005$  or, as a limit:

$$r < 0.37\% \text{ at } 90\% \text{ C.L.}$$

This result is inconsistent with the value of about 1% suggested by the MARK III results.

P791 can be expected to approach a 90% CL limit on mixing of 0.1%, a value which begins to test theoretical models. The data will also provide a test of the anticipated DCSD rate which would provide an equivalent of 0.3%.

### Rare Decay Modes

Rare decay modes including flavour changing neutral current processes, semi-leptonic, and non-Leptonic Decays can be more fully examined with a higher statistics charm data sample. Also, charmed baryon states could be studied. Mark III has reported the observation of  $D_s^{*+} \rightarrow \eta \pi^+$  and set a limit on  $D^{*+} \rightarrow \mu^+ \nu_{\mu}$  of  $7.2 \times 10^{-4}$  (6). E691 has examined the decays  $D^0 \rightarrow e^+ e^-$ ,  $\mu^+ \mu^-$ ,  $\mu^+ e^-$  (7) and have measured the rate for  $D^0 \rightarrow K^- e^+ \nu_e$  (8). Also, hadronic branching fractions can be measured more accurately. Current Mark III values are given in several references (9,10,11). Several dozen charmed baryons have been observed by the E400 (12-15) and CLEO (16) groups. With an order of magnitude more charm decays than E691 and E769, P791 would significantly enhance our knowledge of all of these topics.

### Double Charm Events

Currently, only a small number of events in which both charms are observed have been recorded. Of these events, many are not fully reconstructible and one of the charmed particles is only tagged. Although the total number of charm pairs is large for Mark III, their sample of totally reconstructed pairs is very small (10). Emulsion and bubble chamber experiments report less than a hundred total charm pairs. Completely reconstructed events number in the dozens (18,19). E691 claims to have on the order of 100 fully reconstructible charm pair events (20). The proposed experiment would significantly enhance this sector of study.

### Other Comparisons

Various schemes for triggering have been examined by different groups. The use of an Impact parameter trigger employed by WA82 was expected to provide a rejection factor of about 50, but has since proven to be less effective, although final results are not complete (21). The reliability of an Et trigger has been demonstrated by E691 and E769 and gives a charm enrichment factor of 3 over interaction triggers.

A large number of groups anticipate future running to accumulate higher charm statistics, though it is difficult to cover them exhaustively. The preliminary data reported here for WA82 was for only the first of two runs and, with further improvements to their beam, trigger and vertexing, they may accumulate a large charm sample in the next CERN running period. Experiment WA84, also employing the OMEGA spectrometer, was tested during the last running period at CERN and will run again. Although E687 was limited by the fire during the last run, they have indicated that they intend to increase their photon beam energy and make the modifications necessary to also obtain a very high statistics charm sample. In the more distant future SELEX, which would employ a Hyperon beam, might effectively produce charmed baryon states (22).

## B. Beauty Experiments

Two fixed target experiments at CERN have observed beauty events. WA75 observed one  $B^- B^0$  pair in emulsion (1), and WA78 obtained 13 trimuon events from  $\pi^-$ -uranium collisions, with a beam energy of 320 GeV (2). This second experiment obtains a cross section for  $b\text{-}\bar{b}$  pairs of  $(4.5 \pm 1.4 \pm 1.4)$  nb/nucleon, higher than the perturbative QCD prediction of 0.7 to 2.0 nb. The analysis of dimuon events from WA78 yielded 29 positive muon pairs and 35 negative muon pairs (3). Combining these three data samples gives a cross section of  $(2.0 \pm 0.3 \pm 0.9)$  nb per nucleon. The UA1 measurement of the  $p\bar{p} \rightarrow b\bar{b} X$  cross section  $(1.1 \pm 0.1 \pm 0.4 \text{ micro-b})$  is in good agreement with the ISAJET prediction of 1.7 micro-b (4).

There are several sources of uncertainty in these cross section calculations. Especially at lower values of  $\sqrt{s}$ , the relative contributions of perturbative and non-perturbative QCD terms is not known. Also, the contributions from terms of order higher than  $\alpha(s)^2$  have not been completely calculated. Additional inputs to the calculation which contribute to the uncertainty of the cross section are the mass of the  $b$ -quark, the  $Q^2$  evolution scale for  $\alpha(s)^2$ , the gluon and quark structure functions, and  $A$ -dependence. A good measurement of the  $b\bar{b}$  cross section is essential for the future development of both fixed target and collider beauty experiments.

We will isolate events containing beauty by selecting D events that have evidence that the D is from B decay. Two useful tags will be the mass difference between the B and D in the event, and the location of the D vertex. Since the branching ratio for  $B \rightarrow D$  is nearly 100%, the branching ratio \* acceptance for such events will be similar to the branching ratio \* acceptance for D events. Using the cross section calculations of Berger (5), we expect to partially reconstruct 500 B events during the experiment. Additional inefficiencies will enter and we project only 60 fully reconstructed beauty decays in phase I. Table VI.B summarizes these expected yields and those for other experiments and proposals with the information coming largely from Garbincius (6) or, using similar assumptions about the cross section and running periods.

This is a conservative approach to studying beauty physics with fixed target experiments. The major upgrade, the DA system, is a logical extension of the proven and successful system used in E769. Once this new system is running, then the maximum number of events with beauty will be recorded on tape in a given running period. During the offline analysis, various filters will be applied to obtain the optimal signal to noise ratio in each channel. The results of this experiment will guide future efforts by studying the effectiveness of various data filters, and by measuring the beauty cross section.

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Table VI.A Comparison of Charm Experiments

Experiment (ref.)	Beam	Target	Vertexing -Trigger	Trigs	Total Charm	Mixing	Rare BR	Charm pairs (=fully reconstr.)
NA27 LEBC-EHS (19)	360 GeV/c Pi-	LH2	Bubble Ch.	265K	114			53(12)
NA27 LEBC-EHS (23)	400 GeV/c p	LH2	Bubble Ch.	1M *	134			
E743 LEBC-MPS (24)	800 GeV/c p	LH2	Bubble Ch.	500K *	82	----with 40% of film analysed----		
NA32a (25)	200 GeV/c pi-,K-,p	Si	Si-Interact	40M	200			
NA32b (25)	230 GeV/c pi-,K-	Si+CCD	Si-K+K- K+,p,+	17M	85 Lambda c 530 D	----with 75% of data analysed----		
WA58 (18)	20-70 GeV Gamma	Emulsion	Emulsion	17K	45			36
MARK III (2,9,10,11)	e+e-	Psi (1370)	No vertexing	48K	27.7K D0D0 20.3K D+D-	.01 **		(~400)
ARGUS (4)	e+e-	Upsilon(2S) Upsilon(4S)	No vertexing			<.014		(162)
CLEO (16)	e+e-	Upsilon(4S)	No vertexing					
E653	800 GeV/c p 600 GeV/c pi+	Emulsion	Si-Muon	6M 9M	1600 D0, 1600 D+ 1250 D++, 385 D*0 62 Ds, 160 Lambda c 24 ---- With 80% of electronic data analysed			
E691 (5,7,8,20)	av.150 GeV Gamma	Be	Si-Et	100M	12K	<.0050 ***		(~100)
E400 (12-15)	800 GeV neutron	W,Si,Be	MWPC-Interact	45M	60 Cas.c+ 74 Sig.c++ 58 Sig.c 0	D0-->K0K0		
E687 (1987 data)	av.210 GeV Gamma	Be,Si	Si	70M	4K(Est.)	---- Not analyzed		
E687 (Next run)	av.250 GeV Gamma	Be,Si	Si	500M	50K(Est.)	---- Projected		
E769	250 GeV/c P,K,Pi (+&-)	W,Cu,Al,Be	Si-Et	500M	6K(Est.)	---- Not analyzed		
WA82 (21)	340 GeV/c Pi-	W,Si	Si-Imp.par.	10M	2K(Est.)	--Projection from 5% of data from 1st run		
WA82 (Next Run)	340 GeV/c Pi-	W,Si	Si-Imp.par.	10M	10K	---- Projected		
P791	500 GeV/c Pi-	W	Si-Et	10G	100K	---- Projected		(~2000)

\* These represent triggers in the fiducial volume of the bubble chamber.

\*\* Limits set by Mark III on particular rare decay modes(6):

D+ --&gt; Eta Pi+

Observed

\*\*\* Limits set by E691 on particular rare decay modes (7,8):

D0 --&gt; et e-

&lt; 8E-5

D0 --&gt; Mu+ e-

&lt; 8E-5

D+ --&gt; Mu+ Neumu

&lt; 7.2e-4

D0 --&gt; Mu+ Mu-

&lt; 1E-4

D+ --&gt; Pi+ Mu e

&lt; 2E-4

Table VI.B Comparison of Beauty Experiments\*

Experiment (status)	Beam	Target	Vertexing -Trigger	Trigs	Total B Production	Anticipated B Yield	Measured B Yield
WA75 (Ref.1)	350 GeV/c Pi-	Emulsion	Emulsion-Muon	1.5M			1
WA78 (Ref.2)	320 GeV/c Pi-	U	-Muon, E missing	22M			13 (3 mu)
E653 (1985 data)	800 GeV/c p+	Emulsion	Emulsion, Si	6M		5	
E653 (1987 data)	600 GeV/c Pi-	Emulsion	Emulsion, Si	9M		14	
WA82 (1987 data)	340 GeV/c Pi-	W, Si	Si-Imp. par.	10M	1500	50-100	
WA84 SCIFI (1987 test, next run)	360 GeV/c Pi-	SCIntillating Fibers	Si-Interact.	15M	670	200-300	
E771 (next run)	800 GeV/c p	W	Si-DiMuon			540	
E706/E672 (1987 data)	530 GeV/c Pi-, p	C, Be	Si-DiMuon		6K Psi's	6	
E706/E672 (next run)	530 GeV/c Pi-, p	C, Be	Si-DiMuon		200K Psi's	200	
E690 (next run)	800 GeV/c p	H	PWC- Track Mult.		700K **	No estimate	
P789 (next run)	800 GeV/c p		Si-Lifetime			1000s	
P791 (next run)	500 GeV/c Pi-	W	Si-Et	10G			
E687	av. 250 GeV Gamma	Be/Si	Si- Hadronic Energy	2.5M	50K	500 part. reconstruct 60 full reconstruct	
P786 (next run)	750 GeV/c Muon	LH2/LD2	Streamer Ch.- Tri Muon		2.5K	3-30	
					100K	1000 Mu+Mu- X	

\* Most of the information for this table is from reference (6).

\*\* Bs from Target fragments produced diffractively.



## VII. PROPOSAL SUMMARY AND REQUESTED APPROVAL

P-791 is a proposal to continue the Laboratory's successful series of heavy flavor experiments. Based on the experience of the previous experiments at TPL, modest upgrades to the apparatus and a new data acquisition system have been proposed. These improvements, in conjunction with the beamline upgrade, offer an order of magnitude more data in the hands of a group whose efficient off-line analysis has led to significant and prompt publications. The requested approval at this time is required for the June 1989 Fixed-Target run.

Similarly the streamer chamber technique, proposed as part of the running in the next Fixed-Target period, has great potential. It is the only triggerable, high resolution,  $4\pi$  device which has a chance of contributing to beauty physics. We request the opportunity to demonstrate this potential in charm physics now.

## Appendix

### Charm Physics with the Yale-Fermilab High Resolution Streamer Chamber in the TPL Spectrometer

#### Outline

- I. Overview
- II. Physics Goals
- III. Characteristics of the Streamer Chamber in TPL
- IV. Streamer Chamber Status
- V. Film Analysis
- VI. Fiducial Volume Trigger
- VII. Schedule and Running Time
- VIII. Costs

#### I. Overview

We propose to operate the streamer chamber simultaneously with a part of the P-791 running. The chamber would serve as an "active" target in the spectrometer. The special properties of the chamber as a detector -  $4\pi$  acceptance, excellent pattern recognition, and high accuracy - would allow the study of aspects of charm physics which are complementary to goals of the purely electronic part of P-791.

We will use a simple trigger consisting of a fiducial volume "finder" in conjunction with the global transverse energy trigger used in E-691 and E-769. We propose to take  $3 \times 10^6$  pictures which will contain 9000 or more charm events.

#### II. Physics Goals

We start by giving the charm rates we expect. The simple trigger (low  $E_t$  + FV) has a very high rate in MHz beams. Therefore the chamber will run at a rate we determine by setting the chamber refire deadtime. At any reasonable rate (e.g. 1 to 10 Hz) we can take many millions of pictures. The result is that an interesting number of charm

events plus the off-line analysis effort determine the reasonable number of pictures. Running at 5 hz for 150 spill-hours gives 3 million pictures at a film cost of \$56K.

Assuming that the fraction of charm production to all inelastics in 500 GeV  $\pi^-$ -nucleon collisions is  $10^{-3}$  and (as shown by E-769) that the low  $E_t$  trigger enhances charm by a factor of 3, we expect one charm event in every 333 pictures. This yields 9000 charm events or 18,000 charm decays.

We also note that the fiducial volume trigger can be set for a rather short fiducial volume so that every event is optimally located in the chamber for the best resolution.

With this sample we can address the following physics:

1. Measurement of inclusive charged and neutral D meson production cross sections over the full range of Feynman  $x$  and  $P_t$ . The topology distinguishes between  $D^0$  and  $D^+/D^-$  and the lifetime (via miss distance) allows the separation of  $D^+/D^-$  from  $D_s$  and  $\Lambda_c$ . Note that these measurements are independent of decay mode. The use of the miss distance distributions to measure lifetimes is discussed in section III.

Note also that negative regions of  $x$  are studied as well as positive  $x$ . This could, for example, be important in looking for leading charmed baryon production in  $\pi$ -nucleon collisions where the "leading" baryon is presumably backward in the center of mass. We note that, even for those events whose tracks miss the spectrometer, the topology (production angle, decay length) gives information on a statistical basis about the production kinematics. Of course, maximum use will be made of the tracks which do go through the spectrometer.

2. Measurement of the correlations between the two D's on an event by event basis: again topology and lifetime allow these measurements to be done over the full  $x$  and  $P_t$  range independent of branching ratios.
3. Measurement of the production cross sections for  $D_s$ , and  $\Lambda_c$ : this can be done from the lifetime curve of charged decays. This measurement is possible (or more precisely, we know that it is possible) because of the recent result of E691 on the  $D_s$  lifetime.

The best lifetimes of the relevant particles are from E-691<sup>2</sup> as listed below :

$D^+/D^-$	1.09	$+(-).03$	$+(-).025$	ps
$D_s$	.47	$+(-).04$	$+(-).02$	ps
$\Lambda_c$	.22	$+(-).03$	$+(-).02$	ps

The three lifetimes are almost perfectly "chosen" for a decomposition of the decay curve. Estimates indicate that a measurement of the  $D_s$  cross section to the ~15% level is possible if  $D_s$  is produced at 10% of  $D^+/D^-$  and  $D^+/D^-$  is 1/4 of charm. Clearly full Monte Carlo studies are in order and are being done.

### III. Distinguishing Characteristics of the Streamer Chamber in TPL

The chamber has three properties which are important for the complementary physics we propose to study.

- 1) Very good acceptance, essentially  $4\pi$  in the center of mass.
- 2) Excellent pattern recognition. We will have a negligible false track rate. There are on the average at least 150 measured points on each track. There will of course be some tracks (very few) which are overlaid by other tracks, however we will see this and exclude them from the analysis. There is also the ability to "see" in as close to the vertex, for each track, as is allowed by track overlaps. Thus, measurements on low energy wide angle tracks begin closer to the vertex than small angle higher energy tracks. Given a  $< 15$  micron demonstrated per point setting error we expect a  $< 50$  micron 2 track resolution. This corresponds to resolving 2 tracks at 2.5 mr by 2 cm. Because of the restricted fiducial region in the charm experiment, tracks will range from 8 - 10 cm long.
- 3) Excellent resolution. Although we have not analysed our best data from the T-755 run yet, the older 40 atmosphere data already give demonstrated streamer setting errors and densities, 15 micron streamer setting error and 1 measured streamer per mm, which would give an impact parameter resolution of 5 microns or less. We have other data, not yet completely analyzed, which clearly have greater streamer densities.

The consequences of these characteristics are as follows:

- a) 1 prong decays will be useful.
- b) The vertexing error will not be degraded for the low energy tracks because we will either see the vertex directly or, if the vertex is determined by pointback, the extrapolation distance will be compensatingly less for low energy (and wider angle) tracks.

c) We measure particle lifetimes from impact parameter (primary vertex miss distance) distributions. We recall that the miss distance distribution measures the lifetime with almost the same power as the direct measurement of the proper time distribution. Monte Carlo studies (done for P-755) as well as an analytic study<sup>3</sup> show that the result of a lifetime determination from a sample of miss distances has a standard deviation 10% larger than a determination from a sample (of the same size) of proper times.

d) Both charms in the event can be detected in almost all cases. We also note that a large fraction of the charm particles observed in the chamber will send their charged tracks through the TPL spectrometer. This sample will allow important checks to be done on the purely topological analysis. Incidentally, in essentially every event some tracks will go through the spectrometer and will be useful in the analysis.

e) The interplay between the spectrometer and the chamber data will also aid in all studies. We will know which tracks did and did not come from the charmed particle decays and the primary vertex. This can be important in physics studies where signals are low and there are significant backgrounds. Recall again that the chamber assignments of track provenance are independent of decay interpretation.

#### IV. Streamer Chamber Status

Traditional streamer chambers operate near 1 atm. with streamer diameters in the 1 mm range. Such conditions are not suitable for studying charm or beauty, since at Tevatron energies these particles will only travel a few mm before decaying.

In 1982, the Yale/Fermilab group began to develop a streamer chamber with much improved resolution. The first generation chamber had exploited higher gas pressures. The streamer size scales as  $1/\text{pressure}$ , while the thermal diffusion of the ionization electrons goes as  $1/\sqrt{\text{pressure}}$ . There is then a pressure beyond which diffusion dominates in track resolution. In a 60 atm. chamber,  $\sigma = \sqrt{t} \mu\text{m}$ , where  $t$  is the trigger delay in  $\mu\text{sec}$  (the time between the initial ionization and the H.V. pulse). For a few  $\mu\text{sec}$  delay, this leads to tracks in the 200-300  $\mu\text{m}$  (full width) range. This was the type of chamber used in the E-630 charm experiment at Fermilab.

To realize the full potential of vertex detection of charm and beauty, track widths of 50  $\mu\text{m}$  or less are needed. This corresponds to 15  $\mu\text{m}$  standard deviations for the diffusion of individual streamers. The second generation diffusion suppressed chamber was developed with this goal in mind. The scheme is:

should be reduced to about 5 ns. To achieve this we will laser trigger the Blumlein pulser.

- A new imaging system will be needed. The chamber is presently being imaged (the lens is borrowed from LEBC) on to the face of an image intensifier tube. In order to obtain the necessary resolution, we may have to split the image over two tubes. We would then recombine the tube outputs with fiber optics so that both will fit on 35 mm film, allowing us to operate the camera with a single pull down per frame advance. A camera used at SLAC is available (the advance time is 68 msec) and can be modified for our use. We are also investigating various image tubes and image disectors.

## V. Film Analysis

In this section we discuss our plans for analysis of the 3 million pictures taken during the streamer chamber run. In summary, we plan to fully digitize ALL the pictures, then enrich the sample by a combination of scanning and cuts based on the spectrometer data, and then fully measure the charm subset.

We note that one of the major strengths of the streamer chamber technique is the  $4\pi$  acceptance of the chamber. This important advantage would be lost if we only measured tracks or events which are totally reconstructed in the downstream spectrometer. As we discussed earlier, there are numerous physics measurements that can be made without requiring full reconstruction of the tracks or events.

Below we demonstrate that we can fully digitize all the pictures, and select and fully measure the charm subset using current technology in a reasonable amount of time.

Note that by digitization we mean transformation of the film record into a computer record, without pattern recognition or streamer or track measurement. By measurement we mean location and measurement of streamers on tracks, and fitting of the measured points into tracks.

We have used with success the linear diode array digitization system developed by L. Voyvodic and collaborators at Fermilab. We have digitized a number of streamer chamber pictures, and base many of our estimates on our experience with the MOMM's at FAF.

Starting with  $3 \times 10^6$  pictures, a digitization pixel size of  $20 \times 20 \mu\text{m}^2$  (well matched to our expected streamer size), a chamber area of  $135 \times 40 \text{ mm}^2$ , and an 8 bit grey scale gives 13.5 Mbyte/picture. We expect zero suppression and data compaction will reduce the data by an order of magnitude, giving 1.35 Mbyte/picture.

Total storage for  $3 \times 10^6$  pictures is  $4.1 \times 10^{12}$  bytes. A Honeywell VLDS tape holds  $5.9 \times 10^9$  bytes, so we can store all the pictures on less than 700 tapes (note: a tape costs approximately \$11.00). One tape drive can easily service several digitizers.

We estimate we need approximately 10 sec to digitize a picture, giving  $3 \times 10^7$  seconds digitizing time for the entire experiment. With 2 digitizers this requires approximately 1/2 year.

A very important part of the event analysis will be selection of the 9000 charm events from the full 3 million event sample. We plan to accomplish this using a computer aided human scanning (recall that at this stage, events are fully digitized and available to a workstation). The computer will display the event to a scanner on a screen using a transformation which magnifies the primary vertex region, expands the angular scale, but where straight lines remain straight (Dreverman transformation). In this coordinate system tracks which miss the primary vertex are easy to detect visually. The scanner should be able to rapidly reject events which have no decay vertices, and flag the events which might have.

Allowing 1 minute to accept or reject an event, and 6 scanners in 3 shifts gives 7500 hours or slightly less than a year to scan the entire data sample. Note that this phase of the analysis can be done in parallel with the digitizing effort.

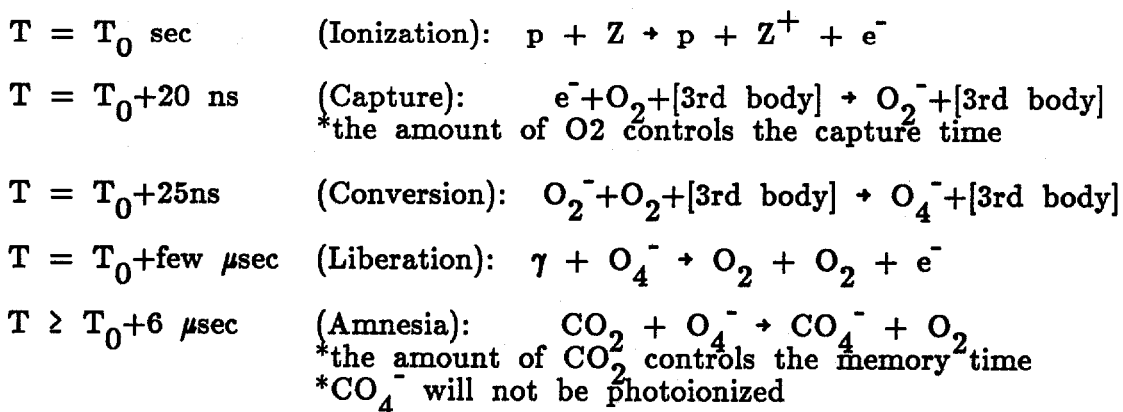
The charm subsample identified through the preceeding analysis will then be fully measured by computer aided human measurers. The human will define regions of the picture containing single tracks in which the computer will find and measure streamers, and then fit them to tracks. Simulations using monte carlo events displayed on a Macintosh computer with a mouse indicate that a measurer can rapidly define roads or regions of the pictures containing single tracks. Allowing 5 minutes/event to measure gives 1700 hours needed to fully measure the charm sample (10000 events, including background). Two scanners working 3 shifts/day can measure the entire charm sample in less than a month. Again this phase can proceed in parallel with the previous ones.

The detailed analysis methodology is under development via our analysis of T755. Exact cost estimates will depend on the final system. However, we note that suitable diode cameras cost ~\$5000, the Honeywell tape drive is about \$45,000, and suitable workstations are becoming readily available.

We have demonstrated above that digitization and scanning of the full data sample, and measurement of the full charm subset is feasible using current technology in a reasonable amount of time. We are vigorously investigating developments and techniques used in the field of pattern recognition and automated measurement, and hope to further simplify and automate the procedures outlined above.

1. Store the initial ionization electrons on an electronegative gas in the form of massive negative ions. The thermal diffusion during the few usec trigger decision is virtually eliminated.
2. Liberate the electrons with a photoionization laser just before the H.V. pulse arrives to form streamers.
3. Build in a memory time by adding a gas which will "steal" the electrons after a suitable trigger delay time. This new species of negative ion should have a negligible photoionization cross section so that subsequent triggers will not integrate old information.

In our chamber we use  $O_2$  to store track information and trace amounts of  $CO_2$  to limit the memory time. The chemistry is:



This scheme was shown to work in preliminary investigations at Yale prior to 1987, and then extensive tests were performed in the Meson Test Beam at Fermilab during the 1987-88 fixed target run (T-755).

Figures A-1 and A-2 show a block diagram and a sketch of the setup tested at Fermilab. Below is a list of the characteristics of the streamer chamber as used in T755.

chamber volume	13.5 cm x 4 cm x 8 mm
gas	up to 60 atm. Ne/He (90%/10%) ~4 psi $O_2$ , ~10 $\mu\text{m}$ Hg $CO_2$
electron capture time	~40 ns
chamber memory time	5-10 $\mu\text{sec}$ (adjustable)

The following is a list of preliminary results of the chamber's performance from T755. All the data was taken at 40 atm.

streamer diameter	50-150 $\mu\text{m}$
$\sigma$ (diffusion)	15 $\mu\text{m}$
visible streamer density	2-4 str/mm
density of measured streamers	1-2 str/mm



We recently digitized some film using an EGG Reticon photodiode array in the Film Analysis Facility (FAF) at Fermilab (numbers in the above table derived from film digitized by humans). Preliminary results are encouraging. One track was measured both by hand and by the diode array. The track was found to have a diffusion standard deviation of  $13.3 \mu\text{m}$  by hand, and  $23 \mu\text{m}$  by the diode array. The diode measured about twice as many streamers as the hand measurement, some of which were very large and should not have been included (like delta rays, for example). Improvements in the measuring algorithm should improve the results. The diode array looks quite promising for resolving two nearby tracks. While a human would see overlapping streamers as one entity, the diode array, using proper pulse height cuts, seemed to distinguish the overlapping streamers. Studies using the diode array will be actively pursued in the coming months. Throughout our association with FAF, Jim Hanlon and his staff of scanners and technicians have consistently provided their support and expertise for which we are grateful.

One potential problem encountered during the T-755 run was a beam-induced streamer background. We are confident that this is not the photoionization of  $\text{CO}_4^-$ , since a drift field applied to the chamber does not sweep out the contaminant (our drift field would sweep out  $\text{CO}_4^-$ ). We feel it is likely due to the particle beam causing outgassing from our electrodes. (The minimum spot size is the test beam was such that the beam struck both electrodes when centered on the chamber.) The contaminants are then photoionized and seen as background streamers on film. This situation was remedied simply by shutting off the gas flow through the chamber during the beam spill. The laser then cleaned contaminants faster than they were produced. There was concern that at beam rates of 2 MHz this scheme would not work (the maximum Mtest beam intensities were typically 20 kHz). However, since the contaminants seemed to be long-lived, we could integrate the meager Mtest beam over a period of several seconds and get within a factor of 3 of the P791 beam rates that we would integrate between triggers. The background was not visible during these tests, so we expect to withstand beam rates of P791 without background. An additional laser pulse between triggers could also be used to assist in the cleaning process if necessary.

Some upgrades need to be made on the chamber before final installation in TPL.

- The present gap of 8 mm between electrodes will be increased to 2 cm. This means a new Marx generator, capable of 750-900 kV, must be purchased.
- The timing jitter between the photoionization pulse and the high voltage pulse is about 30 ns. We hope to run in P791 with a capture time of 20 ns (about 6 psi  $\text{O}_2$ ), so the jitter

## VI. Fiducial Volume Trigger

The fiducial region trigger will use tracking detectors immediately downstream of the streamer chamber to define interactions occurring in the fiducial region of the chamber. These detectors could be PWC's with 1 mm or less wire spacing, however slightly higher resolution would be useful. The very high resolution of silicon micro-strip detectors is better than required but could be used. We are currently investigating the use of plastic scintillating fibers of about 200  $\mu\text{m}$  size transverse to the beam. Such fibers and the required readout are under development for LEP-3<sup>4</sup>. For the purposes of discussing a trigger design, we will assume a detector with 200  $\mu\text{m}$  granularity covering the desired region. The design given below can easily be adapted to other configurations.

Figure A-3 shows the geometry involved. We need only one coordinate for this trigger. We envision either splitting or masking the detector readout so as to ignore the central region. With the geometry and resolution indicated, tracks with angles less than 20mr give little information on the vertex location. The trigger is simplified if the beam is narrow in the direction measured by the tracking detector ( $< 1 \text{ mm}$ ) but a tagging hodoscope in the beam just upstream of the streamer chamber will allow a wider beam. Further Monte Carlo and data studies will indicate just what angular region needs to be covered downstream of the streamer chamber. We assume that the readout of the tracking detector planes proceeds simultaneously from both ends towards the center region (which as stated above is ignored). An angular region large enough to guarantee the presence of a few tracks is covered by the readout. This scheme naturally splits the processing task into two halves.

The processors must identify tracks (aligned hits in the three planes within a tolerance) and require that the tracks intercept the beam track inside the fiducial region (within tolerances). Finding a sufficient number of such tracks will produce a trigger.

Figure A-4 shows a block diagram of the processor. As indicated above two such units (one for each half of the tracking planes) would be used. Since the central region of the planes is ignored and only half a plane is covered by the processor, the multiplicity of hits that must be accommodated is modest. Further, since readout is started at the outer edges of the planes, the processor is most likely to acquire the largest angle tracks which will have the best vertex resolution. We show a processor capable of handling up to 4 hits per half plane. The processor can of course be expanded if further Monte Carlo and studies of the data indicated this is required.

We assume the hits in the plane are encoded rapidly (about 50 - 100 ns per hit is adequate) and passed serially to the processor. Since we

are dealing with a modest number of hits, the parallelism required here is modest. We assume all hits from one plane (Y1) are handled in parallel (4 processing cells) while the hits in the other planes are cycled through the processor ( $4 \times 4 = 16$  cycles). The beam tagging hit (if required) is also passed to the processor. At this point the processor must cycle through all hit combinations in the two downstream planes (Y2 and Y3) to find good tracks and good track intercepts with the beam particle. Figure A-5 shows a processing cell for solving these two problems.

A good track is defined by:

$$| (y1+y3)/2 - y2 | < \text{err}$$

where the lower case letters refer to the actual hit coordinates and "err" is the allowed tolerance. We have assumed the planes will be equally spaced along the beam direction. This equation may be written as:

$$-\text{err} < (y1+y3)/2 - y2 < \text{err}$$

or

$$0 < (y1+y3)/2 - y2 + \text{err} < 2 \times \text{err}$$

This computation is accomplished by a double adder plus a comparator.

To find the intercept of the track with the beam particle (in the beam direction - or Z as indicated in fig. A-3) one may write the track equation as:

$$Z = aY + b$$

One needs to find the intercept "b". Writing the solution in terms of the longitudinal locations of the planes (Z1 and Z3 in fig. A-3) and the track hits in the planes (y1 and y3) one has:

$$b = Z1 - (Z3-Z1) \times (y1/(y3-y1))$$

If a beam tagging coordinate (yB) is used, this equation becomes:

$$b = Z1 - (Z3-Z1) \times ((y1-yB)/(y3-y1))$$

The two coordinate differences are computed in parallel and the results passed to a memory look up unit (MLU) to find the intercept. One need not derive the intercept in the MLU since the desired "answer" is only whether the intercept is acceptable or not (one bit). The track and intercept finding are done in parallel in each cell and the two results together used to produce a "good fiducial track". The number of good fiducial tracks is summed across the entire event and a cut placed on this quantity to produce the final fiducial region trigger (Fig. A-4).

We summarize here the time required to form the fiducial region trigger and the scale of the fiducial processor. We have assumed 50 - 100 ns per hit to find hits in the tracking planes and up to 4 hits per half plane. The half planes will be read out in parallel so that this will involve 200 - 400 ns.

The processing cells involve a double add plus a compare in one path (35ns total) and an add plus an MLU in the other path (40 ns) plus a counter increment (allow 10 ns) plus allowing another 10 ns for set up etc. gives a total of  $40+10+10=60$  ns per cycle. There are a maximum of  $4 \times 4 = 16$  cycles for a total time of  $16 \times 60 = 960$  ns.

The total time for the fiducial region trigger is then:

$$960 \text{ ns} + (200-400 \text{ ns}) = 1160 - 1360 \text{ ns}$$

The scale of this processor is quite modest. Each processing cell requires about 14 - 15 chips. There are 4 cells per processor and two processors so one has a total of about 120 chips for all the cells required. The entire processor plus control logic should fit on one board.

The tracking planes should involve less than 600 channels of readout.

## VII. Schedule and Running Time

The raw rate of fiducial volume low  $E_t$  triggers in a 2 MHz beam is very high on the scale of the streamer chamber dead time. Therefore, the rate at which pictures are taken is determined by our choice of recovery or refire time. We have operated reliably at 5 Hz and could in principle operate as high as 10 Hz.

If we choose 5 Hz as a demonstrated rate we estimate the number of spill seconds needed to acquire the 3 million pictures as  $.6 \times 10^5$  or 167 spill hours.

We propose then to run the streamer chamber for a fraction of the of the 791 run. The relatively short time required for the chamber run would also be helpful in minimizing any interference with the purely electronic part of 791. Repairs (if needed) could wait for natural downtimes.

## VIII. Costs

We summarize the costs to complete and install the streamer chamber below.

		Cost (\$1000)	
		Existing	
		Funds	FY1,2 FY3
1.	High Voltage Pulsing System		
	New Marx Generator	(70)	
	Power Supply for Marx Generator		20
	Coupling Tank for New Marx Generator		10
2.	Reliability improvements and spares inventory		30
3.	New large format image intensifier tubes		140 100
4.	Modifications to SLAC HRO camera for use with streamer chamber.		20
5.	Move chamber and install in TPL.		
	R.F. shielded enclosure		50
	Rework of plumbing, optics, etc.		15
6.	Fiducial Region Trigger.		
	Processor		20
	Tracking detectors and readout		55
TOTAL		(70)	360 100

\* FY1 is the current fiscal year.

#### References

- 1 M. Adamovich, et.al. CERN/EP 86-76, 1986 (WA 58)
- 2 E-691 collaboration, to be published.
- 3 P. Cooper, Yale internal note.
- 4 Dave Kaplan, Talk at E-769 group meeting, 18 February 1988

# TAGGED PHOTON SPECTROMETER E769

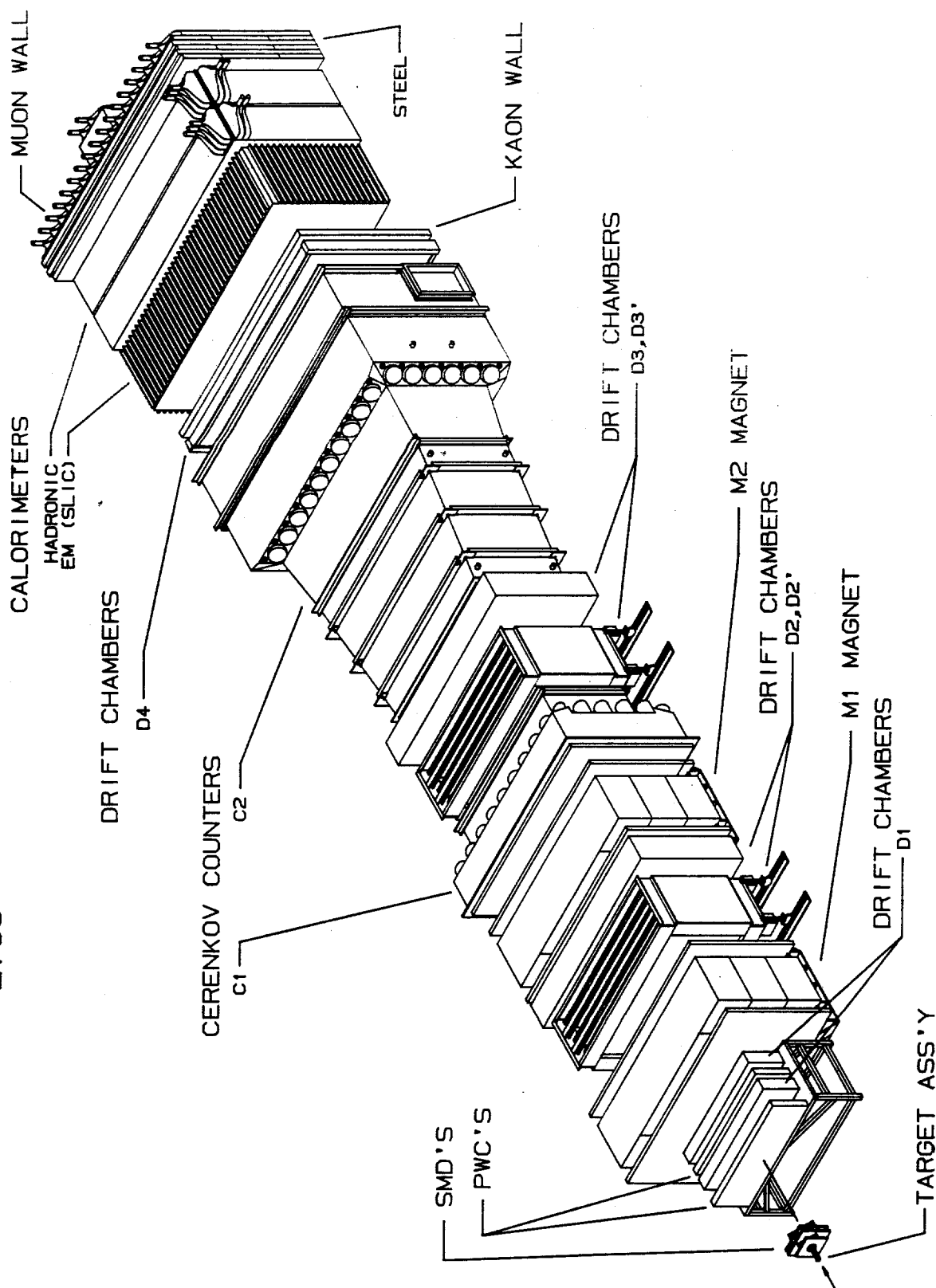
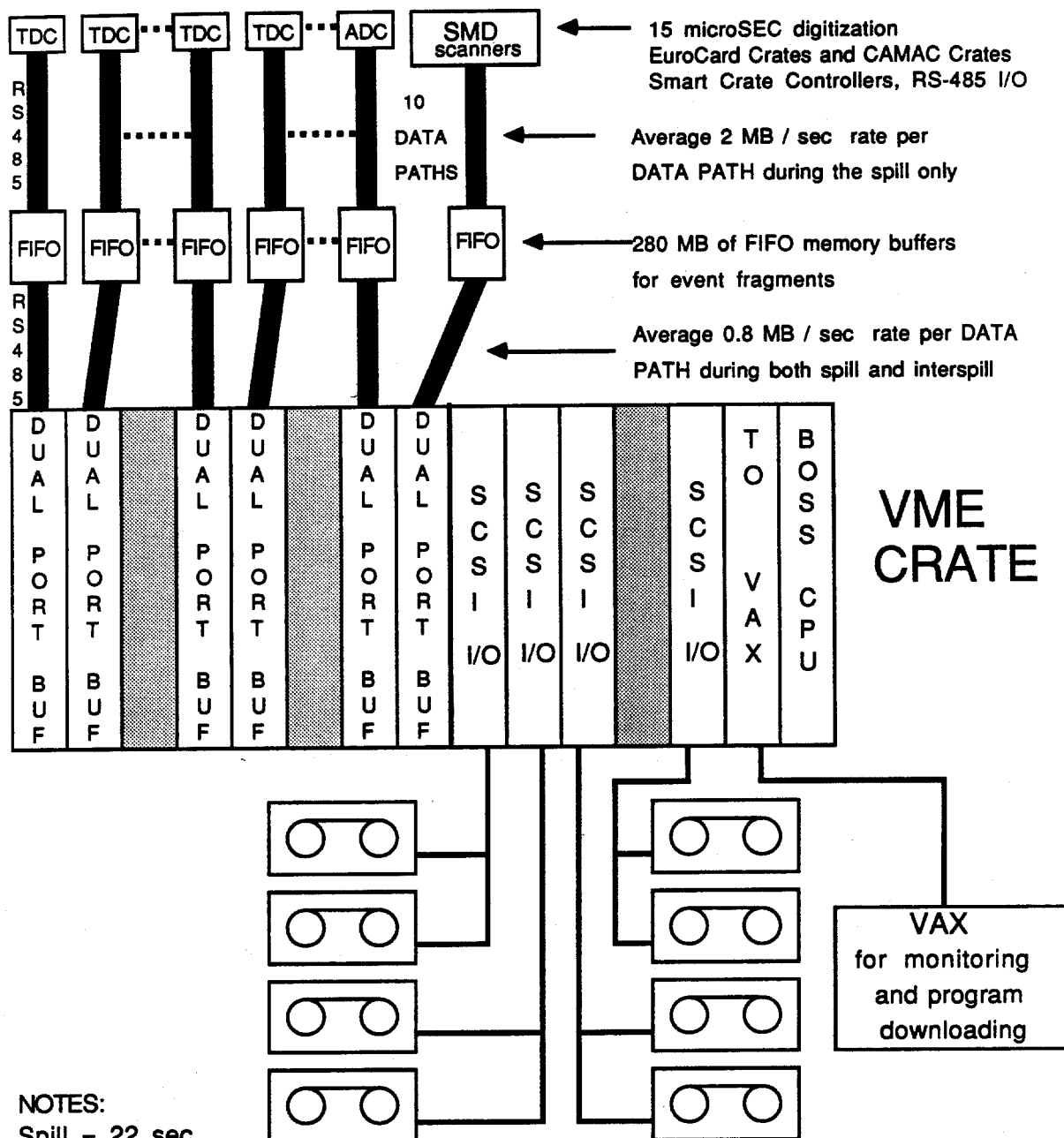


Fig. 1

# P791 5000 EVENT/SPILL-SEC DA



TAPE DRIVES  
2 HONEYWELLS, 4 MB/s, 5.2 GB  
OR  
32 EXABYTES, 0.25 MB/s, 2.3 GB

Figure 2

E791 CHARM PI- BEAM  
 THETA ACCEPTANCE  $D^{+-} \rightarrow K \pi \pi$

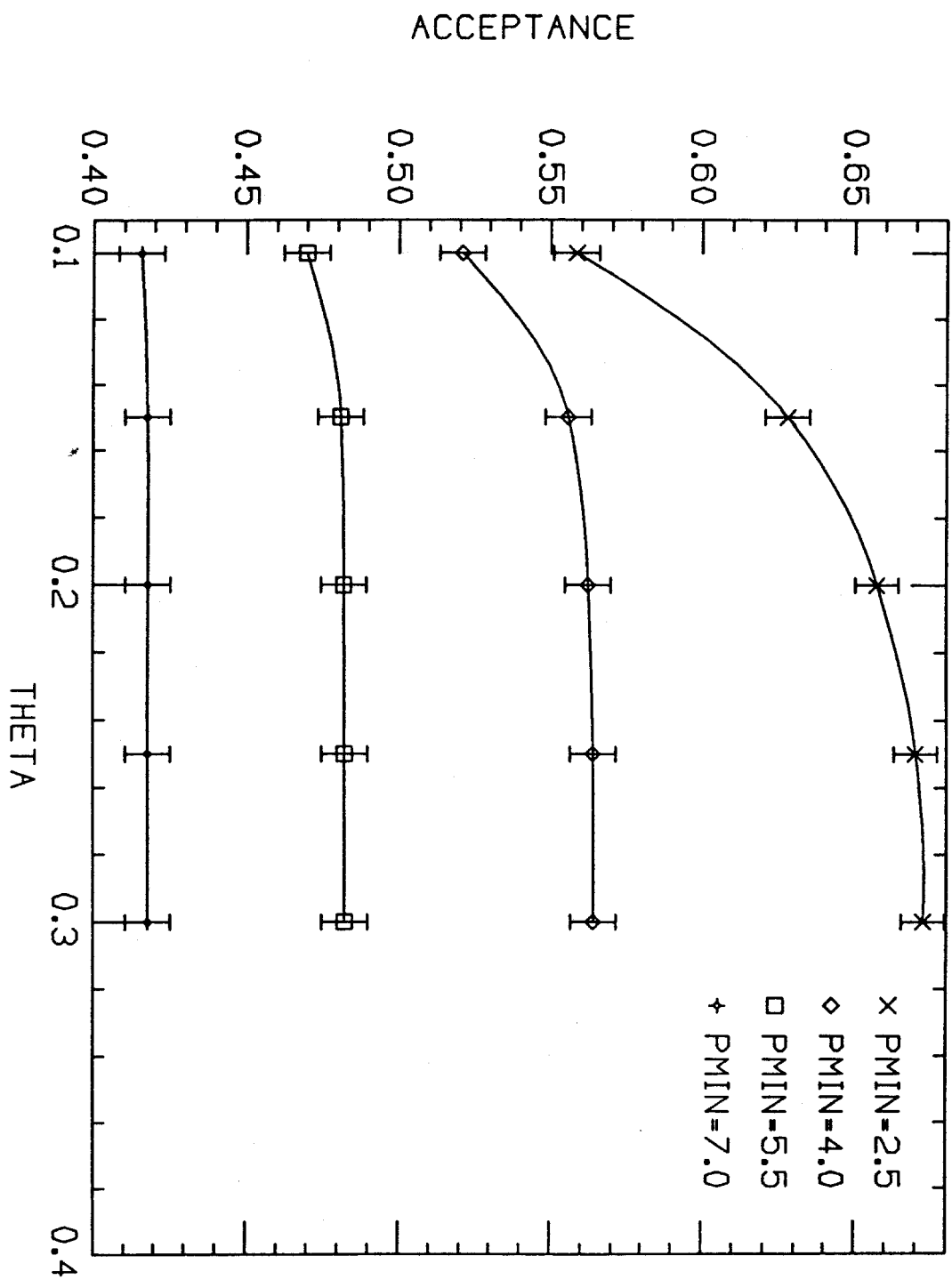


Fig. 3



E791 CHARM  $\pi^-$  BEAM  
THETA ACCEPTANCE FULL EVENT

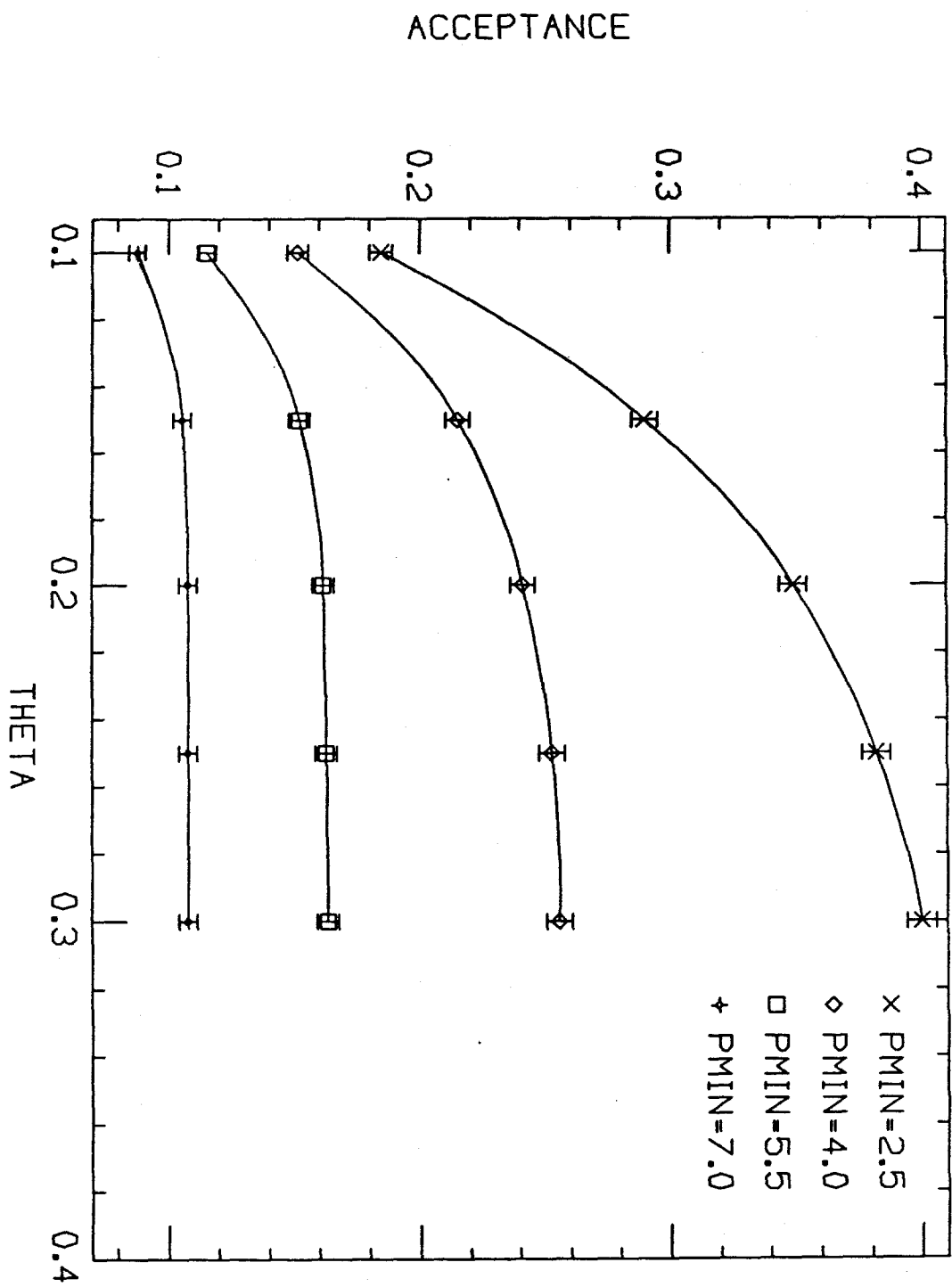


Fig. 4

# E791 BEAUTY PI-BEAM

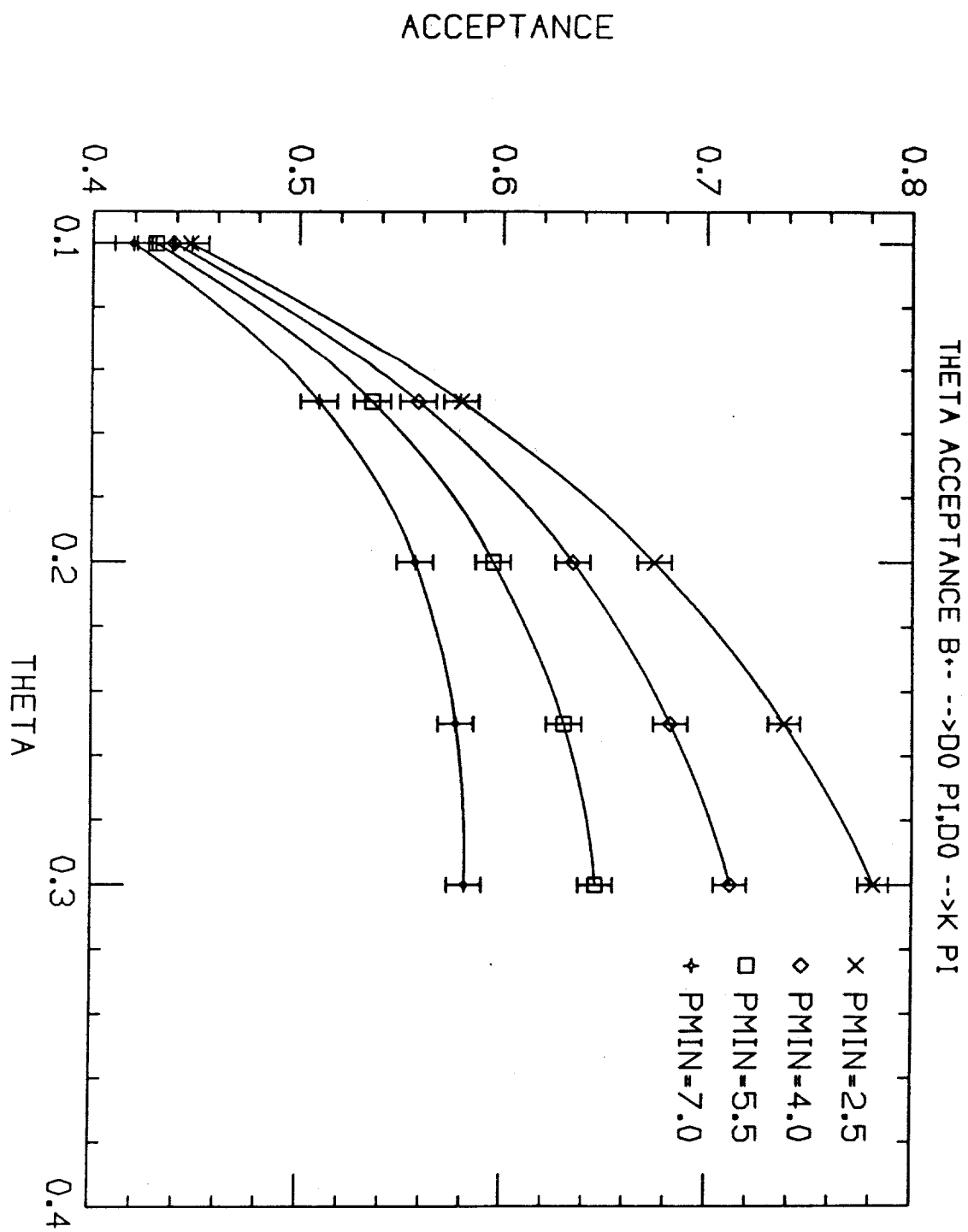


Fig.5

# SECONDARY BEAM RATE (MHZ)

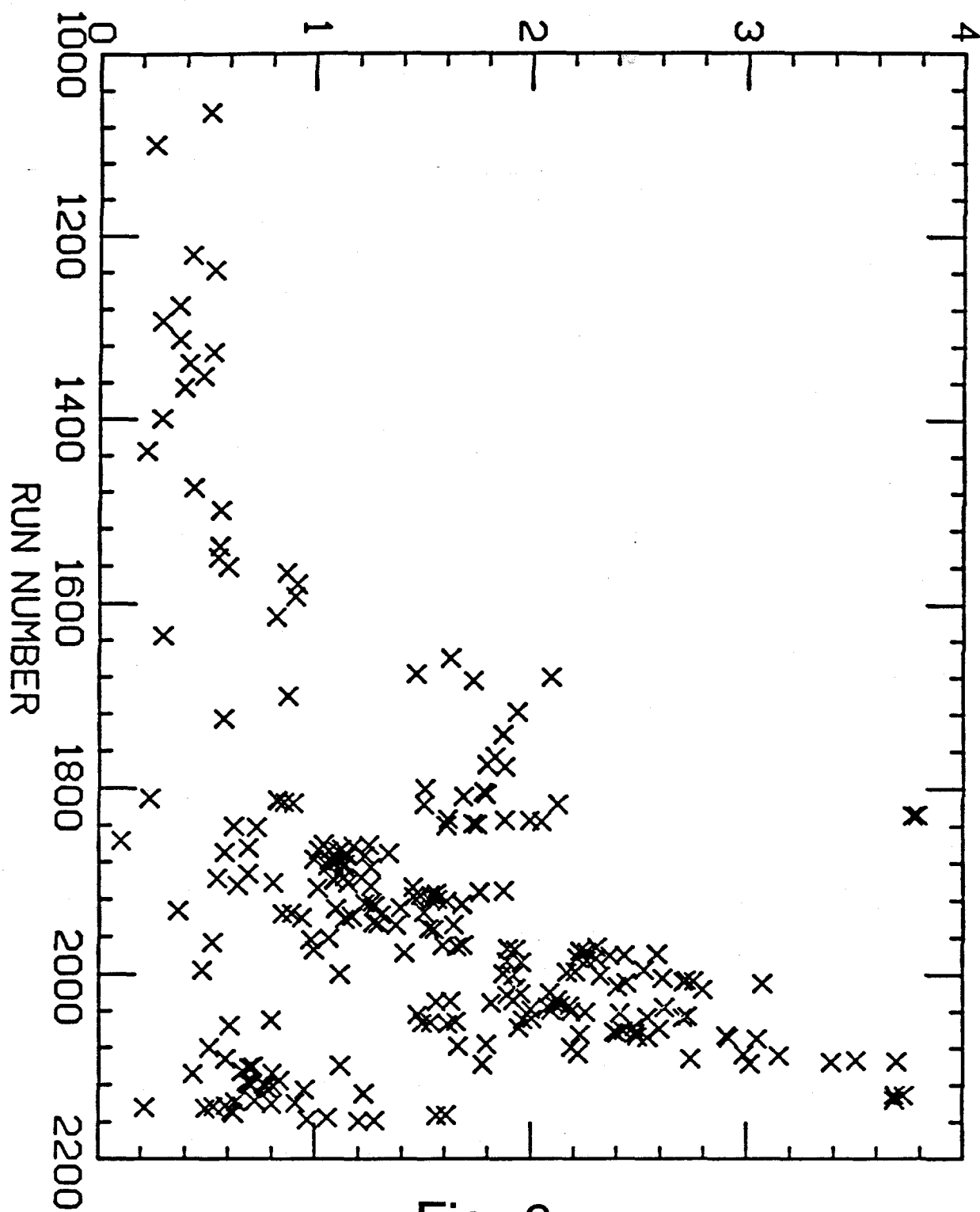


Fig. 6

Figure A-1  
Block Diagram of the Streamer Chamber

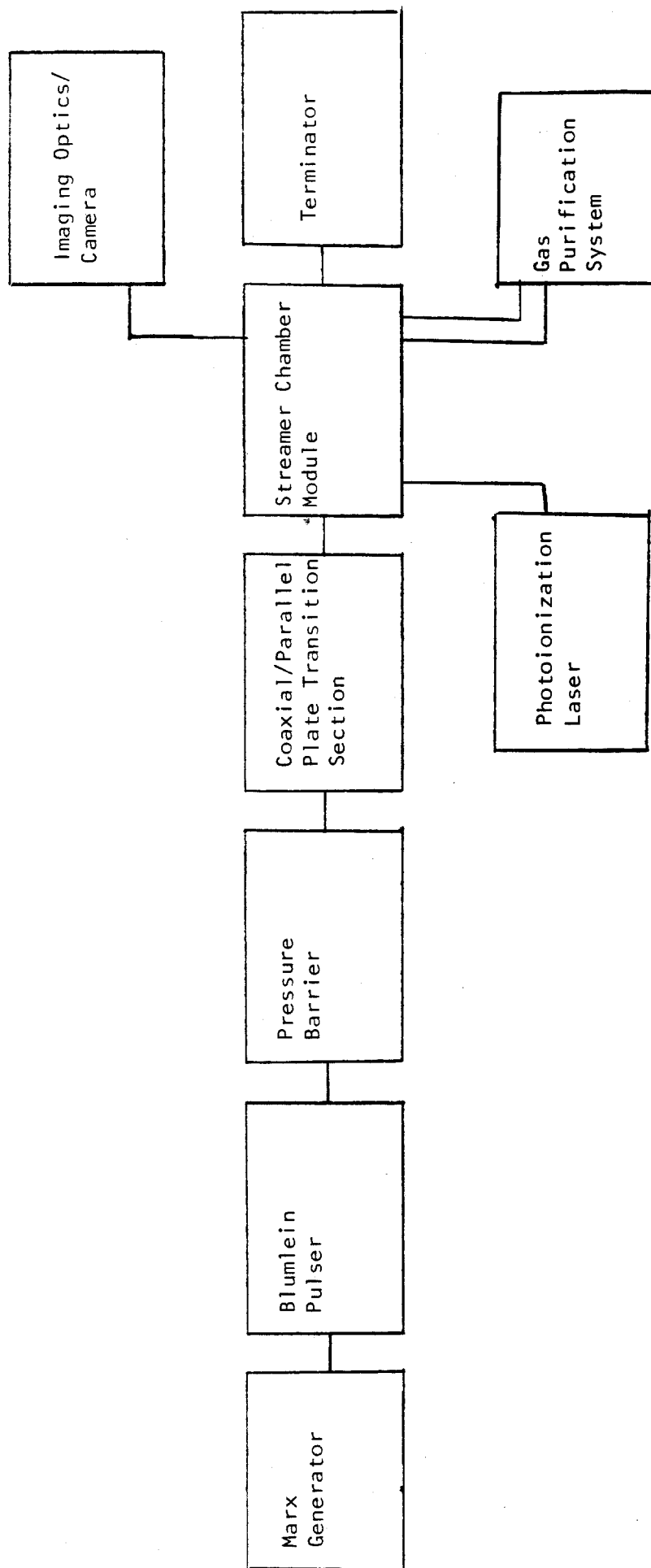


Figure A-2

Drawing of the Streamer Chamber

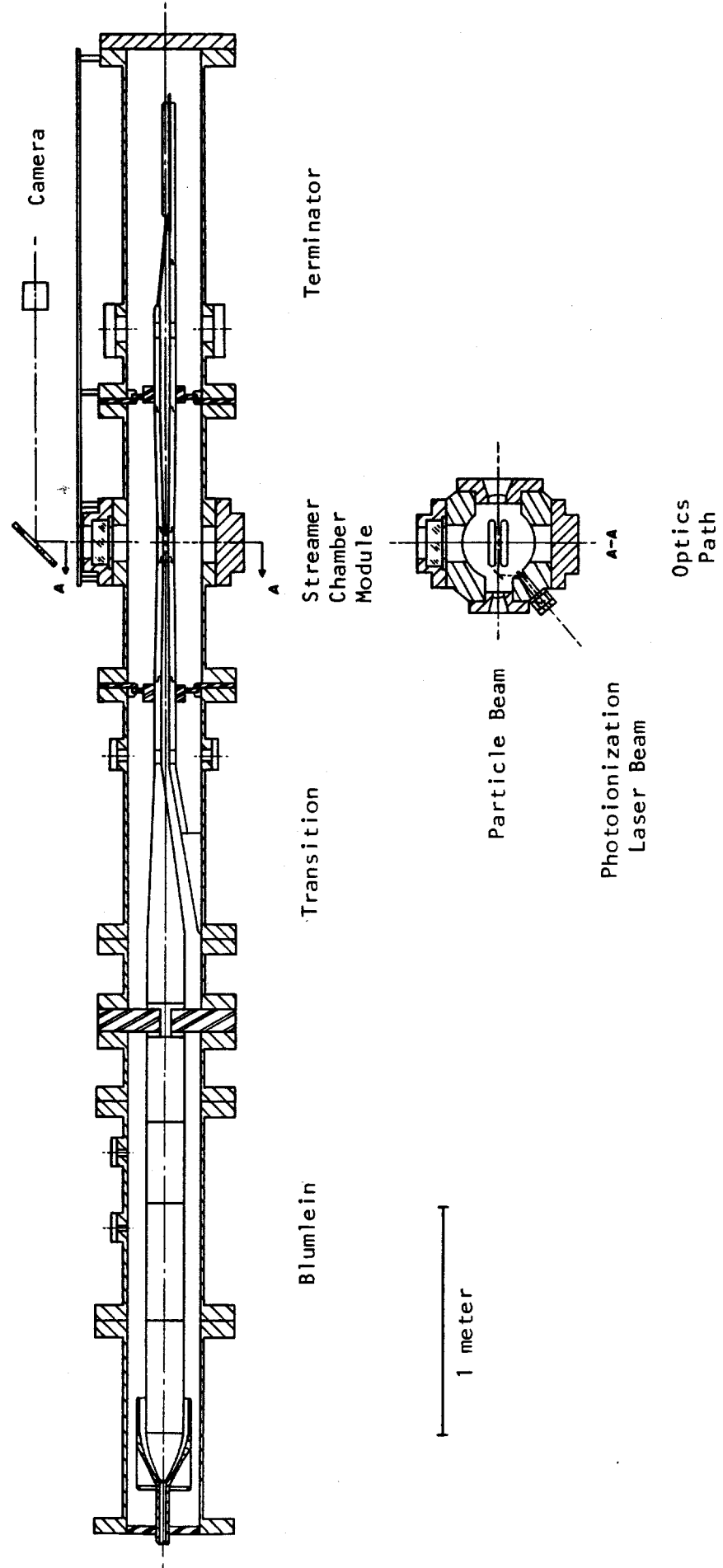
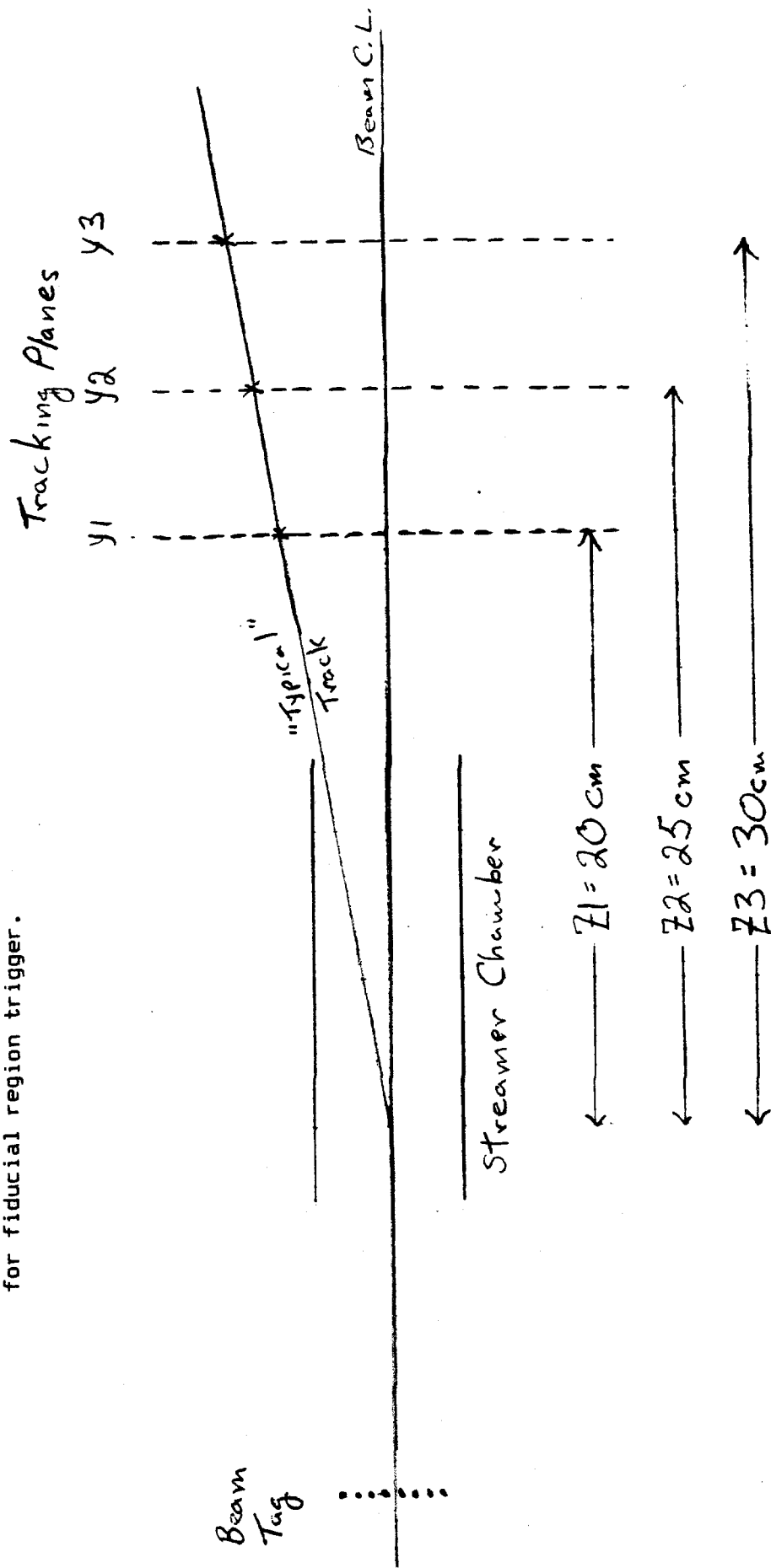


Figure A-3

Layout of Tracking detectors  
for fiducial region trigger.



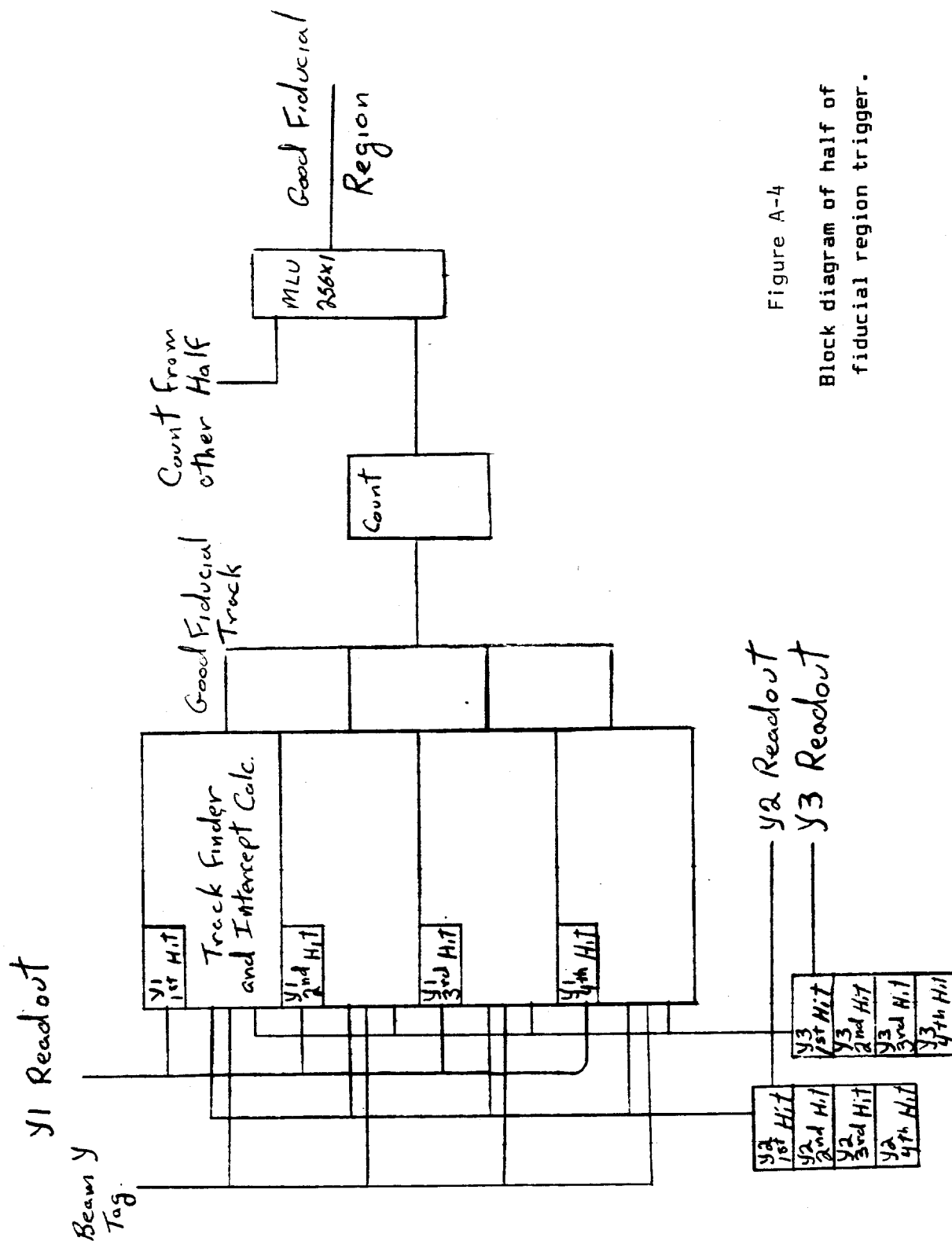


Figure A-4

Block diagram of half of fiducial region trigger.

Figure A-5

Fiducial region trigger calculation cell.

